CERTIFICATE OF TRANSLATION

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Dated this 9th day of November, 2006.

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[Designation of Document] Application for patent

[Reference number] SJ0415

[Filing date] November 13, 2000

[Address] Esq. Commissioner of Patent Office

[International patent classification] B23K 26/06

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[Payment in advance ledger number] 006943

[Payment fee] 21,000

[List of Submitted article]

[Article name] Specification : One set

[Article name] Drawings : One set

[Article name] Abstract : One set

[General power of attorney number] 9102448

[Necessity of proof] Necessary

[NAME OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] METHOD AND DEVICE FOR WORKING PLANNING

[CLAIMS]

[CLAIM 1]

A method of working planning in allocating a plurality of working positions scattered on a workpiece to a plurality of working areas to be simultaneously worked, said method comprising the steps of:

determining an optimal working path for working positions in each working area; and

subsequently determining order of working at the working positions in each working area so that the total working time is minimized in the working areas to be simultaneously worked.

[CLAIM 2]

A method of working planning in determining order of working at a plurality of working areas scattered on a workpiece, said method comprising the step of:

shifting an start point of a working path in each of the plurality of simultaneous working areas so that time for scanning or moving simultaneously performed can be equal, thereby shortening a total working time.

[CLAIM 3]

A working planning method in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in a workpiece, said method comprising the steps of:

solving the traveling salesman problem, thereby minimizing a length of a tour; and

subsequently detecting a longest movement, and determining start and end points so that the longest movement is removed.

[CLAIM 4]

A working planning method in determining order of working by

applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in a workpiece, said method comprising the steps of:

solving a traveling salesman problem to minimize a value produced by removing a longest movement from a tour, thereby obtaining a new tour, and

eventually removing the longest movement, and determining start and end points.

[CLAIM 5]

A working planning method in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising the steps of:

provisionally setting a next working area so as to enclose an end point in a first direction not yet enclosed by the working area;

moving said provisionally set working area in a second direction different from said first direction to enclose an end point in the second direction;

again moving said moved working area in the first direction so as to enclose the end point in said first direction in positions after the movement; and

again moving the re-moved working area in the second direction so as to enclose the end point in said second direction in positions after the re-movement, wherein

said steps of moving are repeated to define the next working area.

[CLAIM 6]

The working planning method according to claim 5, wherein said working area has a square frame orthogonal to said first and second directions.

[CLAIM 7]

The working planning method according to claim 5 or 6, wherein said first and second directions are set to correspond to the moving direction of a workpiece.

[CLAIM 8]

A method of working planning in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising the steps of:

simply dividing an entire surface of the workpiece into the working areas; and

subsequently removing all the working areas without any working position.

[CLAIM 9]

A working planning method in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising the step of:

repeating the step of placing a working area in a position with a largest number of working positions not yet enclosed until all the working positions are enclosed.

[CLAIM 10]

A working planning method, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising the steps of:

provisionally determining area placement; and

subsequently shifting a working area to a neighborhood and removing an unnecessary working area.

[CLAIM 11]

The working planning method according to claim 10, wherein said area placement is provisionally determined by the method according to claim 5.

[CLAIM 12]

The working planning method according to claim 10, wherein said area placement is provisionally determined by the method according to claim 8.

[CLAIM 13]

The working planning method according to claim 10, wherein said area placement is provisionally determined by the method according to claim 9.

[CLAIM 14]

The working planning method according to claim 10, wherein said working area is shifted to a neighborhood and an unnecessary neighboring area is removed, provided that a point independently belonging to said working area stays within the area.

[CLAIM 15]

The laser working planning method according to claim 10, wherein among said working areas, at least two areas joined at an overlapping location are each shifted to a neighborhood and an unnecessary neighboring area is removed, provided that a point independently belonging to said at least two areas stays within said working areas.

[CLAIM 16]

A working planning method in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising,

when the same working position belongs to a plurality of areas, determining said areas to be worked so that number of working positions belonging to each of a plurality of simultaneous working areas is equal.

[CLAIM 17]

The working planning method according to claim 16, wherein

some of the working positions belonging to said plurality of areas are allocated to an area having a greater difference among a

plurality of simultaneous working areas,

some of the remaining working positions are allocated to a area having a smaller difference, and

eventually remaining working positions are distributed equally among both areas.

[CLAIM 18]

A working planning method in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said method comprising the step of:

adjusting an area position so that working positions are gathered to center of each working areas.

[CLAIM 19]

The working planning method according to claim 18, wherein area position is adjusted so that center of an extent of said working positions matches center of the working area.

[CLAIM 20]

The working planning method according to claim 18, wherein area position is set as near as center of gravity of the working positions, provided that the working positions are within the working area.

[CLAIM 21]

A working planning method in working a workpiece placed on a stage, said stage being movable in a plurality of directions, said method comprising the step of:

determining a moving path for said stage by solving a traveling salesman problem with fixed edge points in which a position to load the workpiece to the stage from a loader is set as a start point of the moving path for said stage, a position before moving the workpiece to an unloader is set as an end point.

[CLAIM 22]

A working planning method in simultaneously working a

workpiece placed on a movable stage by a plurality of working units capable of scanning or moving working means within a working area, said method comprising the step of:

determining an distance between the working units so that number of scanning or moving the working means or number of moving the stage is minimized.

[CLAIM 23]

The working planning method according to claim 22, wherein the number of scanning or moving said working means and the number of moving the stage are weighted depending on difference in scanning or moving time.

[CLAIM 24]

The working planning method according to claim 22 or 25, further comprising the steps of:

setting the distance of said working means units;

overlapping scanning or moving ranges of the working means units at that time, thereby obtaining area placement to minimize number of working areas; and

calculating the number of scanning or moving of the working means and the number of moving the stage at the time.

[CLAIM 25]

A working planning method, comprising the steps of:

performing the process according to claim 22 in a different workpiece direction; and

automatically employing the workpiece direction which minimizes the number of scanning or moving the working means or the number of moving the stage.

[CLAIM 26]

A working method performing working determined by the working planning method according to any one of claims 1 to 25.

[CLAIM 27]

A computer program for implementing the working planning

method according to any one of claims 1 to 25.

[CLAIM 28]

A computer readable recording medium recorded with the computer program according to claim 27.

[CLAIM 29]

A working planning device for allocating a plurality of working positions scattered on a workpiece to a plurality of working areas to be simultaneously worked, said device comprising:

working path determining means for determining an optimal working path for working positions in each working area; and

working order determining means for determining order of working in the working positions in each working area so that the total working time in the working areas to be simultaneously worked is minimized.

[CLAIM 30]

A working planning device for planning working in determining order of working in a plurality of working areas scattered on a workpiece, comprising,

working order shift means for shifting a start point of a working path for each of the plurality of simultaneous working areas so that time for scanning or moving performed simultaneously can be equal among the simultaneous working areas, and shortening the total working time.

[CLAIM 31]

A working planning device for planning working in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in the workpiece, comprising,

scanning path determining means for detecting a longest movement after minimizing a round path by solving the traveling salesman problem, and determining start and end points so that the longest movement is removed.

[CLAIM 32]

A working planning device for planning working in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in the workpiece, comprising,

scanning path determining means for solving a traveling salesman problem improved to minimize a value produced by removing longest movement from a tour, thereby obtaining tour, and eventually removing the longest movement to determine start and end points.

[CLAIM 33]

A working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, said device comprising,

area placement determining means for repeating a process for defining a next working area,

said process including provisionally setting the next working area so as to enclose an end point in a first direction not yet enclosed by the working area; moving the provisionally set working area in a second direction different from the first direction so that the area encloses an end point in the second direction; again moving said moved working area in the first direction so that the area encloses the end point in said first direction, and again moving said re-moved working area in said second direction so that the area encloses the end point in said second direction in a position after the re-movement.

[CLAIM 34]

A working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, comprising,

area placement determining means for simply dividing an entire surface of a workpiece into working areas, and removing all the working areas having no working position.

[CLAIM 35]

A working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, comprising,

area placement determining means for repeating a process of placing a working area in a position having the largest number of working positions not yet enclosed until all the working positions are enclosed.

[CLAIM 36]

A working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, comprising,

area placement determining means for provisionally determining area placement, shifting a working area to a neighborhood, and removing an unnecessary working area.

[CLAIM 37]

A working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, comprising,

belonging area determining means for determining a working area, when same working positions belong to a plurality of working areas, said means determining the areas so that number of working positions belonging to each of the plurality of simultaneous working areas is equal.

[CLAIM 38]

A working planning device for working planning in

determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, comprising,

area placement adjusting means for adjusting area positions so that working positions are gathered around the center of each working area.

[CLAIM 39]

A working planning device for planning working in working a workpiece placed on a stage movable in a plurality of directions, comprising,

moving path determining means for determining a moving path for said stage by solving a traveling salesman problem with fixed edge points wherein a position to load a workpiece to the stage from a loader being set as an start point of the moving path for said stage, a position before transferring the workplace to an unloader being set as an end point.

[CLAIM 40]

A working planning device for planning working in working a workpiece placed on a movable stage simultaneously using a plurality of working units capable of scanning working means in a working area, comprising,

unit distance determining means for determining an distance of the working units so that number of scanning or moving the working means or number of moving the stage is minimized.

[CLAIM 41]

The working planning device according to claim 40, further comprising,

workpiece direction determining means for performing the processing by said unit distance determining means in a different workpiece direction, and automatically employing a workpiece direction allowing the number of scanning or moving the working means or the number of moving the stage to be minimized.

[CLAIM 42]

A working device comprising the working planning device according to any one of claims 29 to 41.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[FIELD OF THE INVENTION]

The present invention relates generally to a method and device for working planning at the time of working a workpiece placed on a stage movable in multiple directions using working means capable of scanning or moving in multiple directions. The invention more particularly relates to a working planning method allowing the working time to be shortened, a working method for performing working determined by the working planning method, a computer readable recording medium recorded with a program for performing the working planning method, a working planning device achieving the working planning, and a working device including the working planning device. The working planning method is preferably applied to a laser drilling machine for perforating a plurality of holes in a printed circuit board or the like by laser beam irradiation. According to the method, the distribution state of working positions such as perforation positions in a two-dimensional plane is mathematically interpreted and the operation of the machines is optimally planned.

[0002]

[Prior Art]

In recent years, as there has been an increasing demand for electronic devices having a reduced size and an increased packaging density, multi-layer printed circuit boards having multiple layers of printed circuit boards placed on one another have been provided. In such a multi-layer printed circuit board, conductive layers formed in printed circuit boards layered on one another are electrically connected and therefore these boards are

provided with through holes or via holes. A conductive film is formed in these holes in order to connect the conductive layers in the printed circuit boards.

[0003]

Such holes formed in a printed circuit board tend to have a reduced size (diameter) as small as 0.1 mm or less as recent printed circuit boards have a smaller size and a higher function. A pulse oscillation type laser beam is used to precisely form holes having such a small diameter.

[0004]

The construction of an example of a conventional laser drilling machine using a pulse oscillation type laser is shown in Fig. 1 (general overview) and Fig. 2 (detailed view). The laser drilling machine 10 mainly includes a laser oscillator 12, a beam splitter 14, a left galvano box 20L, a right galvano box 20R, and an XY stage 40 (see Fig. 2). The laser oscillator 12 generates a pulsed laser beam. The beam splitter 14 guides the laser beam output 13 generated by the laser oscillator 12 into two scanning areas 8L and 8R (working areas) of a printed circuit board 6 to be worked (also referred to as workpiece) and halves the output to allow simultaneous working on the right and left sides. The left galvano box 20L includes a left galvano unit 22L (see Fig. 2), which is used to scan the scanning area 8L in the X-axis direction (from the left to the right in Fig. 2) and in the Y-axis direction (from the front to the back in Fig. 2) with the laser beam 13L on the left side reflected by the beam splitter 14. The right galvano box 20L includes a right galvano unit 22R (see Fig. 2) which is used to scan the right scanning area 8R in the X- and Y-directions with the right laser beam 13R passed through the beam splitter 14 and reflected upon a mirror 16. The XY stage 40 includes an X stage 40X for moving the printed circuit board 6 in the X-direction and a Y stage 40Y for moving the printed circuit

board 6 in the Y-direction on the X stage 40X.

[0005]

As shown in detail in Fig. 2, the left and right galvano boxes 20L and 20R include a left galvano unit (also simply referred to as left unit) 22L and a right galvano unit (also simply referred to as right unit) 22R. The left and right galvano units include mirrors 24L and 24R, first galvano mirrors 26L and 26R, first galvano scanners 28L and 28R (also simply referred to as first scanners), second galvano mirrors 30L, 30R, and second galvano scanners 32L and 32R (also simply referred to as second scanners), and fθ lenses 34L and 34R, respectively. The mirrors 24L and 24R are used to reflect the laser beams 13L and 13R, respectively. The first galvano mirrors 26L and 26R are used for scanning with the laser beams reflected by the mirror 24L and 24R, respectively for example in the Y-direction. The first galvano scanners 28L, 28R include galvano drivers for driving the first galvano mirrors 26L, 26R. The second galvano mirrors 30L and 30R direct the laser beams directed in the Y-direction by the first galvano mirrors 26L and 26R in the X-direction perpendicular to the Y-direction. The second galvano scanners 32L, 32R include galvano drivers for driving the second galvano mirrors 30L, 30R. The fθ lenses 34L and 34R deflect the laser beams directed in the X- and Y-directions by the first and second galvano mirrors 26L and 26R, and 30L and 30R, respectively in the direction perpendicular to the surface of the printed circuit board 8 and let the beams out from irradiation apertures (not shown).

[0006]

The left galvano box 20L is for example secured, while the right galvano box 20R has a variable position in the X-direction, and the unit distance (referred to as L-axis value) A is changeable before working.

[0007]

Since the size of fθ lenses 34L and 34R is limited for the cost and quality, the beam irradiation range on the board 6 is limited to rectangular ranges 8L and 8R (referred to as scanning areas) of for example 40 mm × 40 mm having both sides parallel to the X- and Y-axes and centered around the position immediately below the beam irradiation aperture whose position is completely secured during working.

[0008]

Meanwhile, the board 6 is about as large as 500 mm × 600 mm at most for example, and typically larger than the scanning areas. Therefore, in order to perform perforation working over the entire board, the XY stage 40 supporting the board is driven in a desired direction in an XY plane to move the board 6.

[0009]

The laser drilling machine as described above generally operates as follows as shown in Fig. 3.

(1) The board 6 is moved by the XY stage 40.

(2) The left and right scanning areas 8L and 8R are subjected to laser perforation working. These two steps are repeated (referred to as step and repeat) in order to perforate over the entire board. The part of the worked surface irradiated with a laser beam is evaporated, and a hole results in the printed circuit board 6.

[0010]

As shown in Fig. 4, during working in the scanning areas 8L and 8R, a laser beam is irradiated upon the completion of the moving scanning of the first and second scanners 28L, 28R, 32L and 32R in the left and right units 22L and 22R, and the step is repeated.

[0011]

How the devices in the laser drilling machine operate as a system to achieve perforation working will be now described in

conjunction with Fig. 5.

[0012]

There are two inputs used in the operation of the laser drilling machine 10, i.e., CAD data 50 and an input from a window 52 on a PC.

[0013]

More specifically, the perforation conditions such as perforation positions, alignment mark positions for board position registration, and the number of laser irradiation (referred to as shot number) are produced by a CAD system which is not shown and stored in data files. The kind of the board is mostly a packaged board such as a board for mobile phone and a mother board and therefore the arrangement of hole coordinates often has several arranged groups (patterns) of some points. As a result, as shown in Fig. 6, the CAD data 50 is produced by arranging hole coordinates between the start and end signals of a pattern and writing shift amounts for the patterns as many as the number of patterns rather than arranging all the hole position data.

[0014]

A person in charge of working selects a data file in the CAD data 50 on a flexible disc or a network for the input position under the name of working data file using the input window 52 on the PC. Other selective inputs are performed. The selective inputs include information on several items such as whether or not point data is subjected to XY transformation (transformation of the X-coordinate and Y-coordinate of the point data to change the dividing line for the processing regions of the galvano units from the vertical direction to the X-axis to the vertical direction to Y-axis), the position of the right unit 22R (L-axis value), the format of the CAD data 50 (such as Excellon, SHI, and HZ formats).

[0015]

After all the items are input, and the person in charge

presses an input end button (a switch button mainly for input), a planning device 60 performs planning based on the input items. Then, a plan view is produced and displayed on a PC screen. In the plan view, the perforation positions, processings to be separately performed by the left and right units, placement of scanning areas and the like are visibly expressed. The operator checks the plan view and presses the working start button on the window if there is no problem in the view. The operation allows the laser drilling machine 10 to start operating.

[0016]

The machine sends the CAD data 50 and the window input values to the planning device 60.

[0017]

The data planned and produced by the planning device 60 includes five kinds of data, i.e., L-axis value data A, stage stop position (scanning area position) data B, visiting order data C for the stage stop positions, perforation position data D in each scanning area, and visiting order data E for the perforation positions in each scanning area.

[0018]

In the conventional manner, the planning device 60 conduct setting by a method as shown in Fig. 7, using the CAD data 50 and the window input values.

[0019]

The data planned and produced by the planning device 60 will be now described.

[0020]

(1) Unit distance data A

The distance between the left and right galvano units 22L and 22R (L-axis value) A can be set about in the range, for example, from 150 to 300 mm. According to the input window 52 in the PC, the distance is set. The data is used as an instruction

value when the right unit 20R is driven.

[0021]

(2) Scanning area position data B

The operation regions of the units are divided into a regular square lattice at a lattice point distance of 40 mm. An entire rectangular area of 40 mm × 40 mm surrounded by four lattice points is set as a scanning area.

[0022]

(3) Scanning area position visiting order data C

The initial point is at the scanning area in the lower left corner of each unit. As shown in Fig. 8, the trajectory of the stage visiting the scanning areas (referred to as stage path) can take a zigzag path with the line advancing in the X-direction.

[0023]

(4) Perforation position data D in each scanning area

All the perforation positions are labeled for example to specify an area to which each position belongs.

[0024]

(5) Perforation position visiting order data E in each scanning area

The scanning areas are each for example in the shape of a regular square of 40 mm × 40 mm. Meanwhile, as shown in Fig. 9, the regular square region is for example equally divided into ten parts with respect to the X-axis, and then lines parallel to the Y-axis are drawn from the left end of the area at distances of 4 mm. As a result, ten strip-like regions of 40 mm in the X-direction and 4 mm in the Y-direction are formed. The perforation positions of the strip-like regions are sorted with the Y coordinate values. Note however that among adjacent strip regions, one is always in the ascending order and the other in the descending order. The point visited next to the final point in a strip-like region is the initial point of an adjacent strip-shaped

region in the right. The trajectory of the beam irradiation positions (referred to as galvano path) passing through the perforation positions in the scanning area determined by the above operation can generally take a zigzag path with the line advancing in the X-direction.

[0025]

When the planning device 60 completes making data, it informs control device 62 completion of planning. Thereafter, the devices operate in response to an instruction from the control device 62.

[0026]

More specifically, the right unit 22R is driven in the timing in which the control device 62 receives a planning completion signal. Once the movement ends, a movement end signal is transmitted to the control device 62.

[0027]

The laser oscillator 12 lasses in the timing in which the control device 62 receives both movement end signals output from the units 22L and 22R and two scanners 32L and 32R. After a necessary shot number, the lasing end signal is returned to the control device 62. At the point visited last in the area, a signal indicating the end of the laser perforation working at all the perforation positions in the scanning area is returned to the control device 62. If the point is the point visited last in the scanning area and the scanning area is the scanning area visited last, a working end signal is transmitted to the window 52 on the PC.

[0028]

The scanners 28L, 28R, 32L, and 32R are driven in the timing in which the control device 62 transmits the lasing end signal output from the laser oscillator 12 or a movement end signal output from the XY stage 40. When the movement to the next

perforation position is complete, the movement end signal is returned to the control device 62.

[0029]

The XY stage 40 is driven in the timing in which the control device 62 receives a signal output from the scanners 28L, 28R, 32L and 32R indicating the end of the perforation working at all the perforation positions in a scanning area. When the movement to the next scanning area is complete, the movement end signal is returned to the control device 62.

[0030]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

According to the conventional planning method, however, planning is adapted to fill a previously produced form regardless of the distribution of perforation positions, which cannot be always optimal, and a device capable of optimal setting for the following four aspects has been in demand.

[0031]

(1) Point data X-Y coordinate transformation

[0032]

(2) Unit distance setting

These are set by only simple either-or selection in an input window according to the conventional method, which by no means provides optimal setting.

[0033]

(3) Stage path setting

According to the setting method as described above, there could be a scanning area having only one perforation position, in other words the number of scanning areas is not optimized.

[0034]

(4) Galvano path setting

According to the setting method as described above, one movement could wastefully cover the end-to-end distance of a

scanning area, in other words, 40 mm.

[0035]

Note that according to the disclosure of Japanese Patent Laid-Open Publication No. Hei. 11(1999)-149317, when a fuse to be worked in a chip of interest in a semiconductor wafer is fused, the relative positional relation between two heads is determined and maintained, while the optimal inter chip path connecting all the chips to be worked and the optimal path connecting all the fuses and blocks in the chip are determined. However, according to the method, the load of fuse positions to be worked is allocated to two working portions so that ratio of (the number of fuses in two head fly blocks) / (two head fly blocks) can be maximized when the heads are moved into the chip areas to be worked, rather than dividing the region into two. Therefore, the method cannot suitably be applied to the laser drilling machine as intended according to the present invention.

[0036]

The applicant suggests in Japanese Patent Application No. 2000-3180 a method of optimizing a galvano path in a scanning area by solving a traveling salesman problem, while this application is silent about the stage path and the disclosed idea is yet to be developed.

[0037]

The present invention is directed to a solution to the conventional disadvantages described above. It is a first object of the present invention to improve the throughput of a working machine without changing the responsiveness by a laser oscillator, a laser scanning mechanism, a workpiece moving mechanism and the like. According to the invention, two objectives of shortening the total time for moving a workpiece, and shortening the total scanning time by working means such as a laser beam are solved by mathematically interpreting the distribution state of working

positions in a two-dimensional plane, and planning an optimum path.

[0038]

A second object of the invention is to provide a working method to carry out the working planning.

[0039]

A third object of the invention is to provide a computer program to carry out the working planning.

[0040]

A fourth object of the invention is to provide a computer readable recording medium recorded with the computer program.

[0041]

A fifth object of the invention is to provide a working planning device to carry out the working planning.

[0042]

A sixth object of the invention is to provide a working device including the working planning device.

[0043]

[MEANS FOR SOLVING THE PROBLEMS]

According to the present invention, the first object is achieved in allocating a plurality of working positions scattered on a workpiece to a plurality of working areas to be simultaneously worked, by determining an optimal working path for the working positions in each working area, and subsequently determining order of working in the working positions in each working area so that a total working time is minimized in the working areas to be simultaneously worked.

[0044]

According to the present invention, the first object is achieved in determining order of working in a plurality of working areas scattered on a workpiece, by shifting an start point of a working path in each of the plurality of simultaneous working areas so that time for scanning or moving simultaneously performed

can be equal, thereby shortening a total working time.

[0045]

According to the present invention, the first object is achieved, in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in a workpiece, by solving the traveling salesman problem, thereby minimizing a tour length, and subsequently eventually detecting a longest movement, and determining start and end points so that the longest movement is removed.

[0046]

According to the present invention, the first object is also achieved, in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in a workpiece, by solving a traveling salesman problem varied to minimize a value produced by removing a longest movement from a tour, thereby obtaining a tour, and eventually removing the longest movement to determining start and end points.

[0047]

According to the present invention, the first object is also achieved, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by provisionally setting a next working area so as to enclose an end point in a first direction not yet enclosed by the working area, moving the provisionally set working area in a second direction different from the first direction to enclose an end point in the second direction, again moving the moved working area in the first direction so as to enclose the end point in the first direction in the position after the movement, and moving the re-moved working area again in the second direction so as to enclose the end point in the second direction in a position after

the re-movement. The steps of moving are repeated to define the next working area.

[0048]

The working area has a square frame orthogonal to the first and second directions.

[0049]

The first and second directions are set to correspond to the moving direction of a workpiece.

[0050]

According to the present invention, the first object is achieved in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by simply dividing an entire surface of the workpiece into the working areas, and subsequently removing all the working areas without any working position.

[0051]

The first object is achieved, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by repeating the step of placing a working area in a position with a largest number of working positions not yet enclosed until all the working positions are enclosed.

[0052]

The first object is achieved, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by provisionally determining area placement, and subsequently shifting a working area to a neighborhood and removing an unnecessary working area.

[0053]

The working area may be shifted to a neighborhood and an unnecessary neighboring area is removed, provided that a point independently belonging to the working area stays within the area.

[0054]

Alternatively, among the working areas, at least two areas joined at an overlapping location may be each shifted to a neighborhood and an unnecessary neighboring area is removed, provided that a point independently belonging to the at least two areas stays within the working areas.

[0055]

According to the present invention, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by determining areas to be worked so that the number of working positions belonging to each of a plurality of simultaneous working areas is equal when the same working position belongs to the plurality of areas.

[0056]

Some of the working positions belonging to the plurality of areas may be allocated to an area having a greater difference among a plurality of simultaneous working areas, some of the remaining working positions are allocated to an area having a smaller difference, and the eventually remaining working positions are distributed equally among both areas.

[0057]

According to the present invention, the first object is solved, in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece, by adjusting an area position so that working positions are gathered around the center of each working area.

[0058]

The area position may be adjusted so that the center of an extent of the working positions matches the center of the working area.

[0059]

Alternatively, the area position may be set as near as the

center of gravity of the working positions, provided that the working positions are within the working area.

[0060]

According to the present invention, the first object is achieved, in working a workpiece placed on a stage which is movable in a plurality of directions, by determining a moving path for the stage by solving a traveling salesman problem with fixed edge points in which a position to load the workpiece to the stage from a loader is set as a start point of the moving path for the stage, a position before transferring the workpiece to an unloaded is set as an end point.

[0061]

According to the present invention, the first object is achieved, in working a workpiece placed on a movable stage by a plurality of working units capable of scanning or moving working means within a working area, by determining an distance between the working units so that the number of scanning or moving the working means (such as the number of beam scanning and the number of moving the drill) or the number of moving the stage is minimized. The units are for example a beam irradiation unit capable of scanning with a laser beam in a scanning area and a drill moving unit capable of moving a mechanical drill in a moving area.

[0062]

The number of scanning or moving the working means and the number of moving the stage may be weighted depending on difference in scanning or moving time.

[0063]

The distance of the working units may be set, and the scanning or moving ranges of the working units at the time may be overlapped, thereby obtaining area placement to minimize the number of working areas, and the number of scanning or moving of

the working means and the number of moving the stage at the time may be calculated.

[0064]

According to the present invention, the first object is achieved, by performing the above-described process in a different workpiece direction, and automatically employing the workpiece direction to minimize the number of scanning or moving the working means or the number of moving the stage.

[0065]

According to the present invention, the second object is achieved by performing working (such as laser machining and drilling)determined by any one of the above-described working planning methods.

[0066]

According to the present invention, the third object is achieved by a computer program for implementing any one of the above-described working planning methods.

[0067]

According to the present invention, the fourth object is achieved by storing the computer program.

[0068]

According to the present invention, the fifth object is achieved by a working planning device for allocating a plurality of working positions scattered on a workpiece to a plurality of working areas to be simultaneously worked. The device includes working path determining means for determining an optimal working path for working positions in each working area, and working order determining means for determining order of working in the working positions in each working area so that the total working time in the working areas to be simultaneously worked is minimized.

[0069]

According to the present invention, the fifth object is

achieved by a working planning device for planning working in determining order of working in a plurality of working areas scattered on a workpiece. The device includes working order shift means for shifting a start point of a working path for each of the plurality of simultaneous working areas so that the time for scanning and moving performed simultaneously can be equal among the simultaneous working areas, and shortening the total working time.

[0070]

According to the present invention, the fifth object is achieved by a working planning device for planning working in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in the workpiece. The unit includes scanning path determining means for detecting a longest movement after minimizing a round path by solving the traveling salesman problem, and determining start and end points so that the longest movement is removed.

[0071]

According to the present invention, the fifth object is achieved by a working planning device for planning working in determining order of working by applying a traveling salesman problem to a plurality of working positions scattered on a workpiece or working areas set in the workpiece. The device includes scanning path determining means for solving a traveling salesman problem improved to minimize a value produced by removing a longest movement from a round path, thereby obtaining a round path, and eventually removing the longest movement to determine start and end points.

[0072]

According to the present invention, the fifth object is achieved by a working planning device for planning working in

determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The device includes area placement determining means for repeating a process for defining the next working area. The process includes provisionally setting the next working area so as to enclose an end point in a first direction not yet enclosed by a working area, moving the provisionally set working area in a second direction different from the first direction so that the area encloses an end point in the second direction, again moving the moved working area in the first direction so that the moved working area encloses the end point in the first direction, and again moving the moved working area to enclose the end point in the second direction in a position after the movement.

[0073]

According to the present invention, the fifth object is achieved by a working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The device includes area placement determining means for simply dividing an entire surface of the workpiece into working areas, and removing all working areas having no working position.

[0074]

According to the present invention, the fifth object is achieved by a working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The device includes area placement determining means for repeating a process of placing a working area in a position having the largest number of working positions not yet enclosed until all the working positions are enclosed.

[0075]

According to the present invention, the fifth object is

achieved by a working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The device includes area placement determining means for provisionally determining area placement, shifting a working area to a neighborhood, and removing an unnecessary working area.

[0076]

According to the present invention, the fifth object is achieved by a working planning device for planning working in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The unit includes belonging area determining means for determining scanning areas to be worked. When the same working positions belong to a plurality of working areas, the means determines the scanning areas so that the number of working positions belonging to each of the plurality of simultaneous working areas is equal.

[0077]

According to the present invention, the fifth object is achieved by a working planning device for working planning in determining placement of working areas to be worked by working means based on working positions scattered on a workpiece. The device includes area position adjusting means for adjusting area positions so that working positions are gathered around the center of each working area.

[0078]

According to the present invention, the fifth object is achieved by a working planning device for planning working in working a workpiece placed on a stage movable in a plurality of directions. The device includes moving path determining means for determining a moving path for the stage by solving a traveling salesman problem with fixed edge points in which a position to load the workpiece to the stage from a loader is set as a start

point of the moving path for the stage, a position before transferring the workplace to an unloaded is set as an end point..

[0079]

According to the present invention, the fifth object is achieved by a working planning device for planning working in working a workpiece placed on a movable stage simultaneously using a plurality of working units capable of scanning working means in a working area. The device includes unit distance determining means for determining an distance of the working units so that the number of scanning or moving the working means or the number of moving the stage is minimized.

[0080]

According to the present invention, the fifth object is achieved by workpiece direction determining means for performing the processing by the unit distance determining means in a different workpiece direction, and automatically employing a workpiece direction allowing the number of scanning or moving the working means or the number of moving the stage to be minimized.

[0081]

According to the present invention, the sixth object is achieved by a working device includes any one of the above-described working planning devices.

[0082]

[EMBODIMENTS OF THE INVENTION]

A laser drilling machine according to an embodiment of the present invention will be now described in detail in conjunction with the accompanying drawings.

[0083]

As shown in Fig. 10, a working planning device 70 for a laser drilling machine according to the embodiment of the invention includes an area placement planning device 72 for a multiple-unit (two units in the present embodiment) and a

stage/galvano path planning device 76.

[0084]

The two-unit area placement planning device 72 determines the operation regions of left and right galvano unites 22L and 22R based on the coordinate values of perforation points so that the number of scanning areas (working areas) is minimized, executes X-Y coordinate transformation if necessary, and determines the unit distance A to produce scanning area position data B and perforation position data D in each scanning area.

[0085]

The two-unit area placement planning device 72 incorporates an area placement planning device 74 to enclose all the points in the two-dimensional region with a minimum number of equal size rectangles and determine placement of the rectangles. The loop process is repeated until the optimal unit distance is determined.

[0086]

The area placement planning device 74 plans such area placement that the minimum number of scanning areas is obtained for an area and perforation positions in the area.

[0087]

The input of the stage/galvano path planning device 76 is the scanning area position data B and the perforation position data D, the order of visiting the scanning areas (stage path) and the order of visiting the perforation positions in each of the areas (galvano path) are planned, and scanning area position visiting order data C and perforation position visiting order data E are produced.

[0088]

The processing by each of the devices will be now described in detail in conjunction with Fig. 11.

[0089]

The two-unit area placement planning device 72 performs what

is called "minimization of a one-variable function" as shown in Fig. 12. According to the embodiment, the golden section search, generally known as a minimalizing algorithm for a one-variable function is used. More specifically, when the unit distance A is input to the area placement planning device 74, the stage movement number and "the beam scanning number" or parameters (which will be detailed later) produced by weighting these values can be calculated, and the results of calculation can be regarded as the output values of a function. This is utilized to determine the unit distance which minimizes the output values.

[0090]

Before describing the process of planning in detail, the meaning of the term "the beam scanning number", the reason for minimizing the number of stage movement and "the beam scanning number" and the method of using the area placement planning device 74 incorporated in the two-unit area placement planning device 72 will be described. Between the perforation numbers in certain simultaneous working areas by the left and right units, the larger number is selected and one is subtracted from the larger number to produce a beam scanning number in the certain simultaneous working areas. The sum of the beam scanning numbers obtained for all the simultaneous working areas is referred to as "the beam scanning number." The smaller the beam scanning number is, the better balanced the numbers of holes are between the left and right simultaneous working area. While the irradiation for working with one unit only causes a lot of shots to be wasted, this is less likely to happen in the above case, which could reduce the total working time. It is easily conceivable that the total working time should be reduced for a smaller number of stage movements.

[0091]

This is because the total beam scanning time and total stage moving time occupy a large part of the total working time, and

they can roughly be obtained from the following expressions:

Sum of total beam scanning time = (average beam scanning time) × (beam scanning number)

Sum of total stage moving time = (average stage moving time) × (stage moving number)

If the average values of the beam scanning time and the stage moving time should be/could be reduced by the stage/galvano path planning device 76 and if the beam scanning number and the stage moving number can be minimized using the two-unit area placement planning device 72, the total working time must be reduced.

[0092]

The area placements in the left and right beam irradiation regions at the time point of the determination are in full coincidence when one is horizontally shifted to the other by the unit distance, because the unit distance is constant during working. As the unit distance A is set to a value, as shown in Fig. 13, the left ends, for example, of the left and right areas are superimposed, and a temporary region is produced. For the region, the placement of the minimum scanning areas is determined using the area placement planning device 74 and the beam scanning number and the stage moving number for the placement can be calculated.

[0093]

The use of the area placement planning device 74 as described above allows the stage moving number and the beam scanning number to be produced for an arbitrary unit distance as shown in Fig. 14. More specifically, the object is basically achieved if the unit distance allowing these values to be minimized is for example obtained by the iteration process of several steps according to the method of making a one-variable function minimum such as golden section search.

[0094]

Strictly speaking, the golden section search is "minimalizing" algorithm (an algorithm to discover a local optimum) for a one-variable function rather than a "minimizing" algorithm (an algorithm to discover the global algorithm). Since it is very difficult to obtain the minimum value for a multimodal function in reality, the golden section search which allows the minimal value to be discovered by several steps is employed. In order to obtain a minimal value closer to the minimum value, a heuristic solution such as simulated annealing method may be applied.

[0095]

In reality, the two functions have complicated shapes, and it would be difficult to determine the positions optimizing them both (generally referred to as "multi-purpose optimization problem" (here with two purposes)).

[0096]

Therefore, the average beam scanning time is about in the range from 1 to 3 msec, the average stage moving time is about in the range from 0.2 to 0.4 sec, and therefore the beam scanning and the stage movement with a weight of about 100 to 400 (=β) can be set, so that

G (beam scanning number) + $\beta \times$ S (stage moving number)

can be minimized. Here, β is obtained from experiments. This is sometimes referred to as a "weighting parameter method."

[0097]

By the operation, the two-purpose optimization problem can also be reduced to a one-purpose optimization problem.

[0098]

Note that the beam scanning number G can be multiplied by a coefficient γ as follows:

$$\gamma \times G + \beta \times S$$

[0099]

Since a calculator generally operates faster with integers than with decimal fractions, if the value of β obtained from experiments is a decimal fraction in the general expression, the G+β×S as a whole may be multiplied by a suitable integer (times γ) as follows:

$$\gamma \times G + \gamma \times \beta \times S$$

wherein β could be considered as being substituted by γ×β.

[0100]

If β=0 and γ=1, the expression represents G, in other words, the beam scanning number. If β=1,γ=0, the expression represents S, in other words the stage moving number. In this problem, the unit distances to minimize G and S are expected to be close, and therefore the time required for calculation can be shortened by optimizing only one of them.

[0101]

More specifically, as shown in Fig. 12, the coordinates of perforation positions are input in step 101.

[0102]

Then, by steps 102 to 104 and steps 105 and 107, the area placement planning device 74 calculates the scanning area number and the beam scanning number at the minimum value for the unit distance (about 100 mm) and the maximum value for the unit distance (about 300 mm) or parameters produced by weighting these numbers.

[0103]

Herein, the unit distance A is at least 100 mm and at most 300 mm as is the conventional case. The optimal unit distance is clearly at a position near the position of width × 1/2, while it could be smaller than 100 mm or larger than 300 mm depending on the kind of board. The lower limit, 100 mm might not be changeable because of the physical width of the unit, while the upper limit of 300 mm may be variable. The minimum and maximum

values, 100 mm and 300 mm are set at the initial position in the process described above (steps 102 and 105), while the area minimum position could not be included in the range or any distance in the vicinity of 100 mm might be apparently too short and might not be worth checking depending on the size of the board. As a result, the initial position can be set in a flexible manner depending on the size of the board.

[0104]

Then in step 108, the unit distance A is set again at an appropriate position (based on the golden section ratio for example) between the immediate two previous positions, and the scanning area number in the position is calculated by the area placement planning device 74 in steps 109 and 110.

[0105]

In the step 110 in Fig. 12, if the calculation result of $\gamma \times G + \beta \times S$ is judged to be minimum, the loop ends in the step 111, and if it is not minimum, the loop returns to the step 108.

[0106]

If the process exits the loop in the step 111, the area number and the unit distance at the time are stored, and the point data is subjected to X-Y coordinate transformation in step 112, and the loop process from the steps 102 to 111 enclosed by the broken line is executed again.

[0107]

Thus, the X-Y coordinate transformation of data allows the X- and Y- axes of the original data to be vertically sectioned, the unit distance A can be optimized for both and the more suitable distance is selected so that the beam scanning number and the stage moving number are less. For a board as shown in Fig. 15, for example, calculation can be executed for sectioning both in the X- and Y- directions and the optimal one among the results can be selected as shown in Fig. 16.

[0108]

Note that if the board is shifted by 90°, the operator must be notified of the shift. Alternatively, there may be a rotating mechanism at the loader loading the board onto the laser working machine, and the board may be rotated automatically.

[0109]

By the comparison as described above, in step 114 in Fig. 12, the unit distance with the minimum stage moving number and the minimum beam scanning number is defined. If the X-axis of the original CAD data is sectioned, X-Y coordinate transformation is once again performed for returning to the original.

[0110]

In this stage, the unit distance and approximate area placement are obtained. While the area number is minimized, scanning areas might sometimes overlap. Therefore, the process proceeds to step 115, and it is determined in which scanning area perforation positions in the overlapped part are included in. More specifically, the labels (numbers) of scanning areas to which all the perforation point positions belong are defined.

[0111]

More specifically, in Fig. 17, the areas F and G overlap, and there are regions W(1) and W(2) overlapping both areas F(1), F(2) and G(1) and G(2) ((1) for the left unit and (2) for the right unit). In this case, as given by the following expression, the number of holes in the left and right simultaneous working areas are equally distributed so as to minimize the sum of the number of holes in the area with the larger number of holes between the left and right areas F and the number of holes in the area with the larger number of holes between the left and right areas G. This process can reduce the time for processing.

[0112]

Min(Max(number of holes in F(1), number of holes in F(2)) +

Max(number of holes in G(1), number of holes in G(2))

...(1)

[0113]

Now, assume that as shown in the upper part in Fig. 18, there are perforation positions in the left unit for 30 holes belonging only to the area F(1), for 20 holes belonging only to the area G(1) and for 60 holes belonging to the overlapping area W(1), while in the right unit, there are perforation positions for 10 holes only belonging to the area F(2), for 40 holes only belonging to the area G(2), and for 50 holes belonging to the overlapping area W(2). If all the holes are mechanically and automatically made to belong to the area previously determined for example, as shown in the middle part in Fig. 18, there are 90 holes in F(1), 20 holes in G(1) in the left unit, while there are 60 holes in F(2) and 40 holes in G(2) in the right unit. Therefore, the number of galvano shots in the areas F is 90, and the number of galvano shots in the areas G is 40, i.e., 130 in total.

[0114]

In contrast, when the number of holes to be worked at a time is equalized according to the present invention, as shown in the lower part in Fig. 18, there are 55 holes in F(1) and 55 holes in G(1) in the left unit, while there are 55 holes in F(2) and 45 holes in G(2) in the right unit. Therefore, the number of galvano shots is 55 in the areas F and 55 in areas G, i.e., 110 in total, which is 20 shots less than that by the conventional method.

[0115]

The process of distributing holes in overlapped part will be described. Here, it is assumed that the order of executing overlapped part distribution process is determined for example a random order or an order from the largest overlapped number to the smallest overlapped number. Here, the number of holes is

expressed with small characters as f(1), and g(1). Here, f(1) and f(2) are the numbers of holes belonging to positions in the areas F in the left and right units, respectively and not overlapping G, g(1) and g(2) are the numbers of holes belonging to positions in the areas G in the left and right units, respectively and not overlapping F and fg(1) and fg(2) are the number of holes in the overlapping parts W1 and W2 between areas F and G in the left and right units. |f(1)|, |g(1)|, |f(2)|, and |g(2)| are the numbers of holes belonging to the areas F(1) and G(1) in the left unit and the areas F(2) and G(2) in the right units.

[0116]

Then, the specific process is as shown in Fig. 19 for example and in step 201, f(1)-f(2) and g(1)-g(2) and their absolute values are calculated. Then in step 202, as denoted by the arrow A in Fig. 20 showing examples of numerical values, a number of holes is taken from the overlapping part and added to the area having a greater absolute value and a smaller number of holes. Then in step 203, as denoted by the arrow B in Fig. 20, a number of holes is taken from the overlapping part to the area having the smaller absolute value and a smaller number of holes. Then in step 204, as denoted by the arrow C in Fig. 20, the number of holes remaining in the overlapping part is equally distributed to areas F and G, and the process is completed.

[0117]

The above steps determine how many perforation positions in the overlapping part are taken and distributed to areas F and G. Meanwhile, which perforation position is distributed to area F or G is not determined. The distance from the center of F is obtained for all the perforation positions in the overlapping part, and positions nearer to the center F are distributed based on the number to be distributed to F, in other words, a heuristic method is applied.

[0118]

Note that the method of distributing the holes in the overlapping part is not limited to this, and as shown in Fig. 21, positions nearer to the center of each area may be distributed to the area.

[0119]

After the step 115 in Fig. 12, in step 116, the center of the scanning area is fine-adjusted using the present position of point data in the original area 8, and the points are gathered in the center of the adjusted area 8', so that the working precision is improved. More specifically, as shown in Fig. 22, the fine-adjustment is made with the center of the extent of the perforation position (the average of the minimum and maximum values for each axis). Alternatively, as shown in Fig. 23, the adjustment is made so that the center of the gravity of the perforation positions is in the center of the adjusted area 8'. In the latter case, if there is a point P apart from the area, adjustment is made to the further extent to cover all the perforation positions by the area. In the example shown in Fig. 23, the Y-axis may be shifted to the position of center of the gravity but if the X-axis is shifted to the position of the center of the gravity, a point P is out of the area, and therefore the central position is shifted to the limit position to cover all the perforation positions.

[0120]

The operation is not particularly effective in reducing time, while it is effective in improving the working precision. This is because the central part provides high precision in connection with aberration of the fθ lenses 34L and 34R.

[0121]

In practice, this can be implemented by the following method. The method can be a substitute processing according to which data

is input using a window 52 on a PC and the above steps are simplified.

[0122]

According to the substitute processing method, point data patterns are used, and a general process of processing according to the method is shown in Fig. 24. Fig. 25 shows a candidate for the unit distance according to the method.

[0123]

According to the method, for both cases of dividing the unit operation region perpendicularly to the X-axis and Y-axis, the area number for each of the following cases is obtained by the area placement planning device 74. In other words, they are the case of determining as the unit distance "the distance from a left end in which area a point is located to a position where a dividing line of the unit is shifted from a position corresponding to half the width in which area the point is located to the point location" and the case of determining as the unit distance "the shift of a pattern all between the minimum value for the unit distance (about 100 mm) and the maximum value (about 300 mm), when CAD data includes pattern information." Then the smallest area number among all is selected.

[0124]

In the example shown in Fig. 25, the optimal unit distance is the shift amount of the maximum pattern A, i.e., 260 mm or a half (board horizontal size 560 mm/2) i.e., 280 mm.

[0125]

According to the method, unlike the example shown in Fig. 12 in which the unit distance is determined by the calculation to an appropriate position, those unit distances between the minimum value and the maximum value among the pattern shift amounts are all subjected to the golden section search in steps 302 to 305. The other features are the same, therefore denoted by the same

reference characters and not described.

[0126]

Meanwhile, the area placement planning device 74 incorporated in the two-unit area placement planning device 72 determines placement of rectangular areas when a minimum number of equal size rectangles (regular square for example) enclose all the points in the two-dimensional region. The device allows the minimized scanning areas (and therefore the minimized stage moving number).

[0127]

The process of determining the area placement using the device will be now described in conjunction with Fig. 26.

[0128]

Here, assume that in each process, the present position (X, Y) of interest is at the lower left corner vertex of an area (regular square). In each process, the position of the area is updated.

[0129]

In step 401, the coordinates of perforation positions are input.

[0130]

Then, in step 402, the perforation positions are sorted based on the values of the X-coordinates. In steps 406, 409, and 411, the area position is updated in the negative or positive direction on the X-axis. This is because to enclose perforation positions (1) from a perforation position with a small value on the X-axis generally, and (2) from a perforation position with a small value on the Y-axis while the X-axis and Y-axis values are updated so that in one area determination loop, areas can be prevented from overlapping as much as possible.

[0131]

The device performs two steps of updating the area position

in the negative direction (downward) on the Y-axis (steps 406, 411) and the step of updating the area position in the positive direction on the X-axis (rightward) (step 409).

[0132]

The specific process will be now described in conjunction with Figs. 27 to 32.

[0133]

In Fig. 27, if four areas E1 to E4 are defined and the position of the fifth area E5 is searched, points whose covering areas are not defined are searched in the sorted order in step 403. The leftmost point P1 not enclosed is found in step 404 as shown in Fig. 28, and the area E5 enclosing the point P1 is provisionally produced in step 405. Then in step 406, the lowermost point not enclosed in a band region B1 corresponding to the width of the area, more specifically, a part under the present area position E5 whose area is yet to be determined with the minimum Y-coordinate value is searched in order to update the area position downward (area position updating (1)). If no such point is found, the previous position is defined.

[0134]

Meanwhile, as shown in Fig. 29, if the lowermost point P2 is found, the position of the area E5 is moved downward so that the point P2 is positioned on the lower side. If the point is discovered, the value of the Y-coordinate is updated by Y', while if the area at (X, Y') and the already defined area overlaps for an area more than a certain value as shown in Fig. 30, the point with the minimum Y-coordinate value is once again searched in the non-overlapping region e above the greatly overlapping region. If the point is discovered in the region e (Y″), the value of the Y-coordinate is updated by Y" which is the minimum Y-coordinate value in the region e, and overlapping is prevented. If no such point is discovered in the region e, the area position to be

processed next is updated rightward, so that the position should be updated rightward to avoid overlapping, and therefore the value of Y-coordinate is directly updated by Y'.

[0135]

When the value of the Y-coordinate is updated in step 407, the process proceeds to step 409, the position of the area E5 is moved rightward as shown in Fig. 31 in order to update the area position, and the value of the X-coordinate is updated by the value of a point P3 with the minimum X-coordinate value in the present area (updating of the area position (2)).

[0136]

If the value of the X-coordinate is updated in step 409, the process proceeds to step 411, and the step of again updating the area position downward is performed (updating of area (3)). More specifically, as shown in Fig. 32, the side having the maximum Y-coordinate value on the upper side among the four sides of the already determined areas is searched in the negative direction on the Y-axis from the present area positions (X, Y). Note however that areas which do not have overlapping sides in a prescribed level or more by the downward movement is ignored. The Y-coordinate of the discovered side is Y'. Points with the minimum Y coordinate value whose area has not be determined is searched in the rectangular region B2 which is under the lower part of the present area and whose Y-coordinate value is equal to or larger than Y'. If the point is discovered, the Y-coordinate value is updated by the value.

[0137]

In the processing using the device, there are a first loop for determining one area and a second loop for fine adjustment of an area position rightward and downward. Once the area position is determined, the process exits the first loop and if the area position is not updated in the area position updating steps 409,

411, the process exits the second loop.

[0138]

The above processing is repeated until the area positions are defined, and as shown in Fig. 33, the final position of the area E5 is defined. Then, the process proceeds to the loop for searching the next area. Note that the scanning direction or the updating direction of the area positions is not limited to the described examples, and they may be reversed.

[0139]

As a variation of the processing by the area placement planning device 74, as shown in Fig. 34, local search in combinatorial optimization problem (also referred to as "iterative improvement method) may be applied, area placement excluding areas without points may be produced based on the conventional area placement, and then the area position may be shifted up and down, and rightward and leftward, so that unnecessary areas can be removed one after another.

[0140]

More specifically, as shown in Fig. 35, areas without points are excluded from the conventional areas as shown (A) in Fig. 34, so that the area placement as shown (B) in Fig. 34 is generated as an initial solution. Note that the "solution" is one of possible combinations (solution set) of "area placements (and area numbers) enclosing all the points." A "good solution" refers to a solution with a small area number.

[0141]

The initial solution can be generated by various other methods than the above method. For example, one possible method may be so-called greedy algorithm known for combinatorial optimization problem which repeats the process of "discovering positions enclosing the largest number of non-enclosed points and placing areas" until all the points are enclosed.

[0142]

Alternatively, the area placement determined by the process as shown in Fig. 26 may be an initial solution.

[0143]

Subsequently, in step 502, y is substituted with an initial solution x, and in step 503, a neighborhood N(y) of the solution y is searched. More specifically, as shown in Fig. 36, provided that points independently belonging to an area Ei of interest stay within the area, if the area position is moved to a position in a movable region, and points independently belonging to an area Ej, one of areas neighboring the area of interest Ei are included in the area resulting from the movement, the neighbor area Ej is not necessary. Therefore, the neighbor area Ej is deleted to discover a solution z better than y, and in step 505, the value of the thus discovered solution z is submitted for y, and the step 503 is repeated.

[0144]

In the process of the step 503, once a solution better than y can no longer be discovered in N(y), the process proceeds to step 506 and the value of the present y is set as a solution, and the processing ends.

[0145]

Alternatively, as shown in Fig. 37, provided that points independently belonging to two neighbor areas Ei and Ei+1 joined by an overlapping region, in other words points present in regions other than the overlapping region stay within the two areas, if the area positions are moved to positions in the movable region, and points belonging to a neighbor area Ej are all included in the two areas, the neighbor area Ej is not necessary and may be deleted.

[0146]

Note that the number of areas joined by the overlapping

region may by two or more. More specifically, provided that points independently belonging to n areas Ei, ..., Ei+n-1 joined by an overlapping region (n: 2 or more), in other words points present in the regions other than the overlapping region stay within the n areas, if the n areas are moved to positions in the movable range of the area, and all the points independently belonging to one neighbor area Ej are included in the n areas, the neighbor area Ej is not necessary and may be deleted.

[0147]

The stage/galvano path planning device 76 plans optimization of the order of visiting scanning areas (stage path) and the order of visiting points at the positions to be worked (perforation positions) in each of the scanning areas (galvano path). The basic process by the device is shown in Fig. 38. The device is mainly characterized by application of a generally well known "traveling salesman problem" (a problem to obtain the shortest traveling path through all the cities to come back to the first city: also abbreviated as TSP) or an variation of this general TSP (referred to as varied TSP) as the case may be. In other cases, if it is not necessary to come back after visiting the points, the start and end points for scanning or moving must be determined.

[0148]

Application of the traveling salesman problem depending upon the situation and the determination of the start and end points should be performed particularly in consideration of the following points.

[0149]

In planning a stage path in step 601, an XY stage 40 includes an X stage 40X to cause movement only in the X-direction and a Y-stage 40Y to cause movement only in the Y-direction as shown in Fig. 1, and therefore the end of one movement of the XY stage 40 is at the end of the movement by the two stages 40X and

40Y. In general, the X stage 40X positioned under the Y stage 40Y is heavy, and is less responsive as shown in Fig. 39.

[0150]

Therefore, the moving distance L based on working positions (x1, y1) to (x2, y2) is provided by the following expression, assuming that if the moving distance is equal, the moving time period in the X-direction is a prescribed number (α) multiple of the moving time period in the Y-direction. The constant α is obtained by experiments.

[0151]

$$L = \max\{|x1-x2|, \alpha|y1-y2|\} \quad \ldots(2)$$

wherein max{p, q} represents the larger one of p and q.

[0152]

Alternatively, the moving time period Tx(l) and Ty(l) in the X- and Y- directions can be obtained for a moving distance l and the moving distance can be obtained from the following expression accordingly.

[0153]

$$L = \max\{Tx(|x1-x2|), Ty(|y1-y2|) \ldots(3)$$

[0154]

With regard to the start and end points of the stage path, the start point of a stage path is at the position to load from the loader to the stage, and the end point is at the position of the stage before moving to the unloader as shown in the upper part of Fig 40. A traveling salesman problem with fixed edge points may be solved to effectively shorten the stage operation time.

[0155]

The optimal path for the stage including the start and end points is shown in the middle part of Fig. 40, and the order of visiting on the board at the time (the area visiting direction on the board and the stage moving direction are 180° shifted (reversed) from one another) are shown in the lower part in Fig.

40.

[0156]

In galvano path planning from steps 602 to 604, as for the distance, first and second galvano scanners 28L, 28R, 32L and 32R are provided so that one axis (the X- or Y- axis) independently changes the other axis. Therefore, the end of one scanning operation by the galvano scanners in one scanning area must be the end of scanning by both the first and second galvano scanners. However, the irradiation range to the second mirrors 30L and 30R is generally larger than the irradiation range to the first mirrors 26R and 26L, and therefore the second mirrors have a larger weight than the first mirrors do. Therefore as shown in Fig. 41, the response of the second mirrors is lower.

[0157]

For the above reason, the moving distance M from the perforation positions (x1, y1) to (x2, y2) can be obtained from the following expression (assuming that the moving time of the second mirror is a prescribed number (α') multiple of the moving time of the first mirror for the same distance). The constant α' is obtained by experiments.

[0158]

$$M = \max\{|x1-x2|, \alpha'|y1-y2|\} \qquad \ldots(4)$$

[0159]

Alternatively, the moving distance M can be obtained based on the scanning angles θ and δ of the galvano mirrors from the following expression rather than based on the coordinates on the board.

[0160]

$$M = \max\{|\theta 1-\theta 2|, \alpha'|\delta 1-\delta 2|\} \qquad \ldots(5)$$

[0161]

Another method of setting the distance is from the following expression, while the moving time T'x(m) and T'y (m) in the X- and

Y- directions for the moving distance M are obtained by experiments.

[0162]

$$M = \max\{T'x(|x1-x2|), T'y(|y1-y2|)\} \quad \ldots(6)$$

[0163]

Note that if for example the beam scanning time is unequal between simultaneous working areas in the right and left units as shown in the upper part in Fig. 42, and there is a stand-by time period on one unit side, the start points may be shifted for matching in step 603, so that the beam scanning time periods can be equal, and the total working time period can be shortened.

[0164]

More specifically, if points P1(1) to P5(1) in the left area and points P1(2) to P4(2) in the right area as shown in the upper part in Fig. 43 are to be worked for example, the start point in the right region is changed from P1 to P2 as shown in the lower part rather than in the middle part in Fig. 43, so that the total moving time period can be significantly shortened.

[0165]

With regard to the start and end points of the galvano path, the start and end points can be determined as shown in detail in Fig. 44 by applying the traveling salesman problem to determine a tour, so that the longest distance (the most time consuming) movement Lmax can be removed.

[0166]

Alternatively, if the number of positions to visit is small, a tour is determined as a substitute processing so as to minimize "(tour length)-(largest moving length)," and the longest movement can be excluded, in practice, as shown in Figs. 45 and 46. Among methods using a traveling salesman problem, k-opt or Lin and Kernighan (LK) algorithm allows iteration of the loop of "searching the neighborhood of a solution (tour) and updating with

a neighbor" and the solution is sequentially improved. As a result, if "(tour length)-(largest moving length)" is evaluated as the "solution" of each loop rather than the "tour length", "(tour length)-(largest moving length)" is minimum as the final solution. In Fig. 46, the tour length is smaller on the right side, while if compared based on the "(tour length)-(largest moving length)," the left side is the optimal solution.

[0167]

As possible approaches in the traveling salesman problem used in steps 601 and 602, Nearest Neighbor, Multiple fragment, 2-opt, 3-opt, Lin-Kerrighan, Iterated Lin-Kerrighan, Chained Lin-Kerringhan, Iterated 3-opt, and Chained-3-opt algorithms can be used separately in consideration of the calculation time and effect (path length).

[0168]

[Embodiments]

(1) Two-unit area placement planning device

[0169]

(a) Effect of area placement planning device

For some real board data, the results of applying the area placement planning device 74 to the entire board are given in Figs. 47 and 48. Here, in order to focus on changes in the area number, the processing of dividing the region into two with two units is not employed, and the entire board is used as a single area. The numerical results are given in Fig. 49. While the result differed depending upon various conditions such as the perforation position number and the density of points, a reduction from 10% to 30% in average in the area number was observed.

[0170]

(b) Effect of unit distance optimization

For real board data (perforation position number: 48490), the graph having the unit distance A for the abscissa as the X-

axis is divided into two, the beam scanning number for the first ordinate and the stage moving number for the second ordinate is given in Fig. 50. Here, the area placement planning device 74 is not used, and the scanning areas are determined according to the conventional method. The numerical results are given in Fig. 51. Herein, "halving," "the head of pattern" correspond to the conventional methods.

[0171]

The beam scanning number is 24627, which is improved by about 5% as compared to those by the conventional methods (26111 for the halving, and about 27000 for the head of pattern). Note that the stage moving number (71) is not much different between the optimal position and those by the conventional methods. This is because the area placement was determined based on the conventional area placement method which depends only on the longitudinal and transverse sizes. If the area placement is determined using the area placement planning device according to the present invention, the stage moving number should be different.

[0172]

(2) Stage/galvano path planning device

[0173]

(c) Effect of applying traveling salesman problem

In a foursquare region of 40 mm × 40 mm, perforation positions were generated using random numbers for simulation. Figs. 52 and 53 are diagrams where the abscissa represents the number of perforation positions, and the ordinate represents the average value of one movement by the galvano scanner. As the distance measurement used for experiment, the distance for the same moving speed in the X- and Y- directions is used for the stage and galvano scanners where $\alpha=\alpha'=1$ in the expressions (2) and (4). Here, the result by the conventional methods and that by the application of 3-opt well known as one of traveling salesman

problem approaches are compared. A part of the result is given in Fig. 54. Regardless of the difference in the number of perforation positions, the average value of the distance by one movement of the galvano scanner was improved by about 30% to 40%.

[0174]

As described above, along with the effect of reducing the area number using the area placement planning device, the stage total moving time is surely reduced and improved about by 20 to 30%.

[0175]

As describe above, application of the stage/galvano path planning device according to the present invention surely reduces the total moving time of the galvano scanner approximately by 30% to 40%.

[0176]

In the foregoing, the number of galvano units is two, while the number of galvano units is not limited to this, and may be one, three or more.

[0177]

In the foregoing, the areas each have a regular square shape of 40 mm × 40 mm, while the shape is not limited to this, and the areas may be a regular square, an oblong rectangle or a circle of a different size. The scanning direction is not limited to the typical scanning direction parallel to one side of the area as shown in the upper part in Fig. 55, but scanning may be performed in an oblique direction obtained by concentrically rotating the point coordinates as shown in the lower part in Fig 55.

[0178]

In addition, the means for scanning scanning areas with a laser beam is not limited to the device with a galvano scanner, and may be a hybrid working system (so-called "flush cut system") including a combination of a linear monitor XY stage and a high

speed working head as suggested by the applicant in Japanese Patent Laid-Open Nos. 2000-71089, and Hei 11-144358.

[0179]

The invention is by all means applicable to general working machines (such as a drilling machine with a mechanical drill) using working means other than those with a laser beam such as the laser drilling machine described above. Further, the working planning may be separated from hardware, and may be used in computation service which receives data via the Internet for example, and returns results of computation.

[0180]

[EFFECTS OF THE INVENTION]

According to the present invention, the working position information is mathematically interpreted and the operation of the devices is planned in the optimal manner, so that the time for laser working can be reduced.

[BRIEF DESCRIPTION OF DRAWINGS]

[Fig.1]

A perspective view of a laser drilling machine to which the present invention is applied.

[Fig.2]

A detailed perspective view thereof.

[Fig.3]

A timing chart for use in illustration of overall working operation by step and repeat.

[Fig.4]

A timing chart for use in illustration of working operation in each scanning area.

[Fig.5]

A block diagram of the conventional device system configuration of a laser drilling machine.

[Fig.6]

An example of CAD data.

[Fig.7]

A flowchart for use in illustration of the process of a conventional data setting method.

[Fig.8]

A perspective view of an example of a conventional stage position and path.

[Fig.9]

A plan view showing an example of a conventional galvano scanner path.

[Fig.10]

A block diagram of the structure of an embodiment of a laser drilling machine planning device according to the present invention.

[Fig.11]

A flowchart for use in illustration of overall process according to the embodiment.

[Fig.12]

A flowchart for use in illustration of the processing by an example of a two-unit area placement planning device.

[Fig.13]

A plan view for use in illustration of the principle of how the unit distance is set.

[Fig.14]

A diagram showing the relation among the beam scanning number, the stage moving number, and the optimal unit distance.

[Fig.15]

A diagram showing an example of a board for use in illustration of the usefulness of the XY coordinate transformation.

[Fig.16]

A diagram showing how the XY coordination transformation is performed.

[Fig.17]

A plan view showing an example of area placement when there is an overlap, for use in illustration of the principle of how perforation positions are distributed when there is such an overlap between areas.

[Fig.18]

A diagram showing an example of how the perforation positions are distributed.

[Fig.19]

A flowchart for use in illustration of an example of specific process of overlap distribution processing.

[Fig.20]

A diagram showing an example of distribution.

[Fig.21]

A diagram showing another example of distribution.

[Fig.22]

A plan view showing how the area positions are fine-adjusted in the center of the extent of perforation positions.

[Fig.23]

A plan view showing how area positions are fine-adjusted in the center of gravity of perforation positions.

[Fig.24]

A flowchart for use in illustration of the processing by a variation of a two-unit area placement planning device according to a variation.

[Fig.25]

A plan view showing an example of candidate for the unit distance according to the variation.

[Fig.26]

A flowchart for use in illustration of the area placement planning device according to the embodiment.

[Fig.27]

A plan view showing how the next area position is searched, for use in specific illustration of the process.

[Fig.28]

A plan view showing the state when the leftmost point not yet enclosed is found.

[Fig.29]

A plan view showing the state when the lowermost point not yet enclosed in a band region for the area width is found.

[Fig.30]

A plan view showing an exception processing when there is a large overlap with a defined area.

[Fig.31]

A plan view showing the state when the leftmost point in the next area is found.

[Fig.32]

A plan view showing the state when an overlap is avoided.

[Fig.33]

A plan view showing the state when the next area is defined.

[Fig.34]

A plan view showing the principle of how an area determining method according to a variation works.

[Fig.35]

A flowchart for use in illustration of the process.

[Fig.36]

A diagram showing an example of how an area neighbor is searched according to the variation.

[Fig.37]

A diagram of another example.

[Fig.38]

A flowchart for use in illustration of a stage/galvano path planning device according to the embodiment.

[Fig.39]

A diagram showing an example of difference in the moving time by the stage, for use in illustration of the principle of the present invention.

[Fig.40]

A plan view showing an example of the positional relation between a loader, an unloader and an XY stage and the optimal path.

[Fig.41]

A diagram showing the difference in the moving time by a galvano scanner, for use in illustration of the principle of the present invention.

[Fig.42]

A timing chart for use in illustration of the principle of matching the moving pattern of the left and right units executed with the stage/galvano path planning device.

[Fig.43]

A plan view and a related timing chart showing the effect of shifting the order of visiting one of the left and right scanning areas.

[Fig.44]

A plan view showing how the longest movement is removed after a round path is determined in relation with the start and end points.

[Fig.45]

A flowchart for use in illustration of the process of determining a round path by "(round path) - (longest movement)".

[Fig.46]

A plan view thereof.

[Fig.47]

A plan view showing an example of the effect by the area placement planning device.

[Fig.48]

A plan view showing another example of the effect.

[Fig.49]

A table generally showing how the area number changes.

[Fig.50]

A diagram showing the relation between the beam scanning number and the stage moving number relative to the unit distance, for showing the effect of optimization of the unit distance.

[Fig.51]

A table generally showing the numerical results.

[Fig.52]

A diagram showing in comparison a conventional galvano path and a galvano path to which the present invention is applied.

[Fig.53]

A diagram showing in comparison the relation between the number of perforation positions and the galvano scanner moving distance according to the conventional example and the present invention.

[Fig.54]

A table generally showing the numerical results.

[Fig.55]

A plane view showing a variation of the scanning direction.

[EXPLANATION OF NUMERALS]

6・・・Printed circuit board (Work)

8, 8', 8L, 8R・・・Scanning area

10・・・Laser drilling machine

12・・・Laser oscillator

13, 13L, 13R ・・・Laser beam

14・・・Beam splitter

22L, 22R・・・Galvano unit

40・・・XY stage

42X・・・X stage

42Y・・・Y stage

70・・・Planning device

72・・・2-unit area placement planning device

74・・・Area placement planning device

76・・・Stage/galvano path planning device

[NEME OF DOCUMENT] ABSTRACT

[ABSTRACT]

[OBJECT] Information of drilling positions are mathematically interpreted and operation of machines is optimally planned so that the working time with a laser drilling machine is shortened.

[MEANS FOR SOLVING] With a two-unit area placement planning device 72, the distance between left and right galvano units (unit distance value) A is optimized so that the number of beam scanning and the number of moving the stage are minimized. With an area placement planning device 74, the area position is optimized so that the number of areas is minimized. With a stage/galvano path planning device 76, the distance of moving the stage and the distance of scanning by the galvano scanner are shortened by solving a traveling salesman problem.

[SELECTED FIGURE] Fig. 11

FIG.1

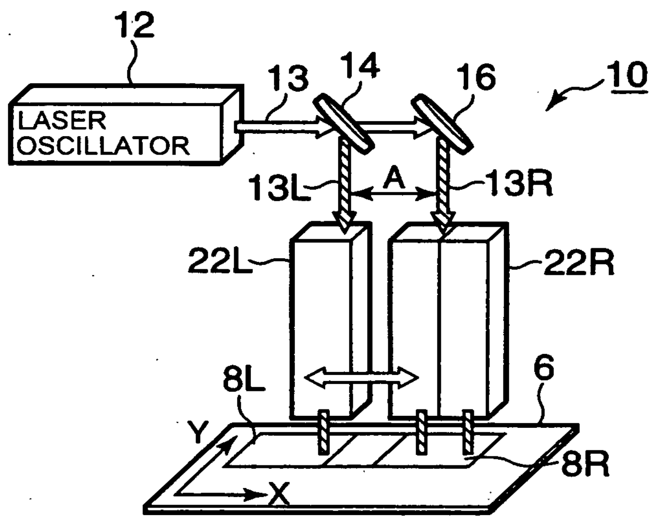

12
LASER OSCILLATOR
13
14
16
10
13L
A
13R
22L
22R
8L
6
Y
X
8R

FIG.2

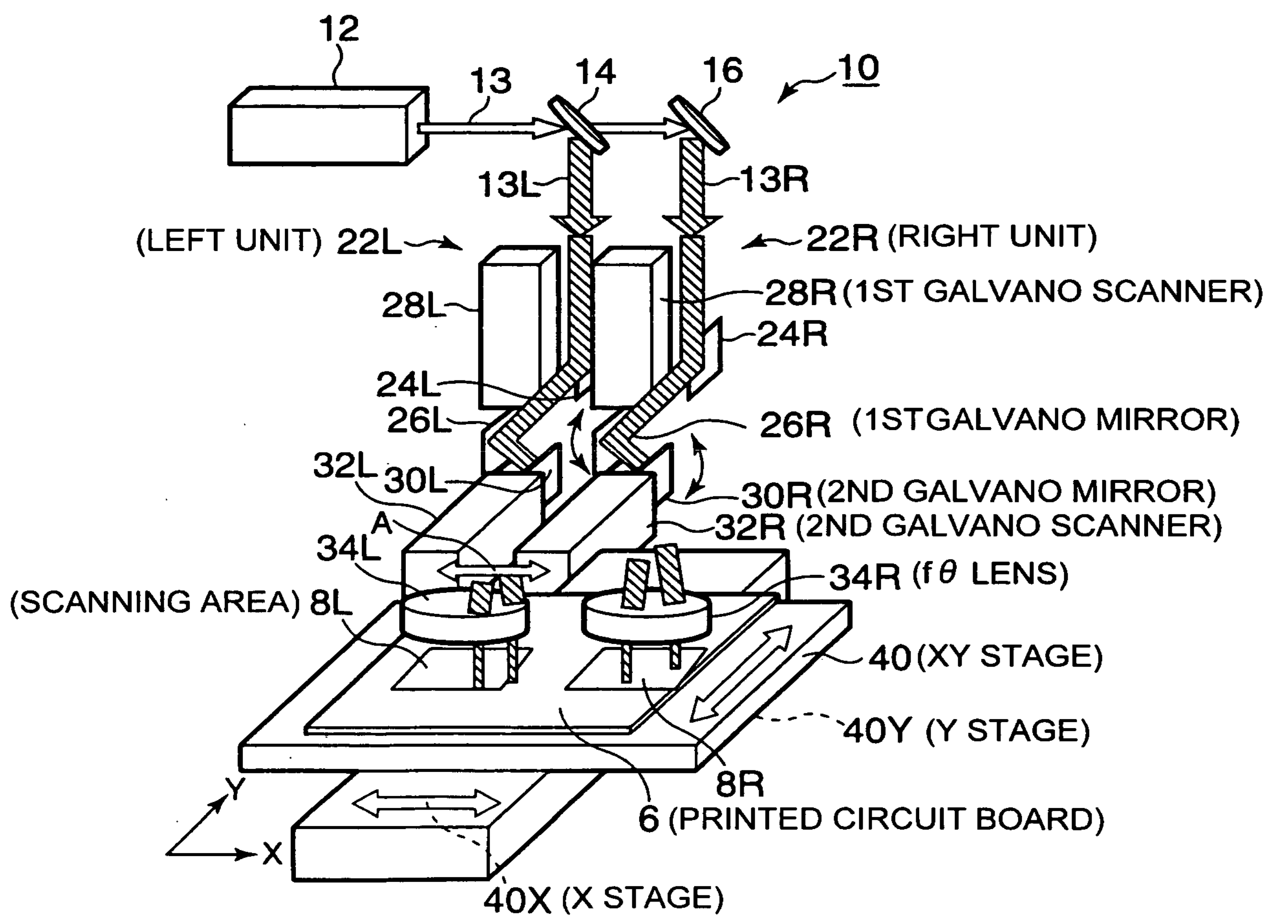

12
13
14
16
10
13L
13R
(LEFT UNIT) 22L
22R (RIGHT UNIT)
28L
28R (1ST GALVANO SCANNER)
24R
24L
26L
26R (1STGALVANO MIRROR)
32L
30L
30R (2ND GALVANO MIRROR)
A
32R (2ND GALVANO SCANNER)
34L
34R (fθ LENS)
(SCANNING AREA) 8L
40 (XY STAGE)
40Y (Y STAGE)
Y
8R
6 (PRINTED CIRCUIT BOARD)
X
40X (X STAGE)

FIG.3

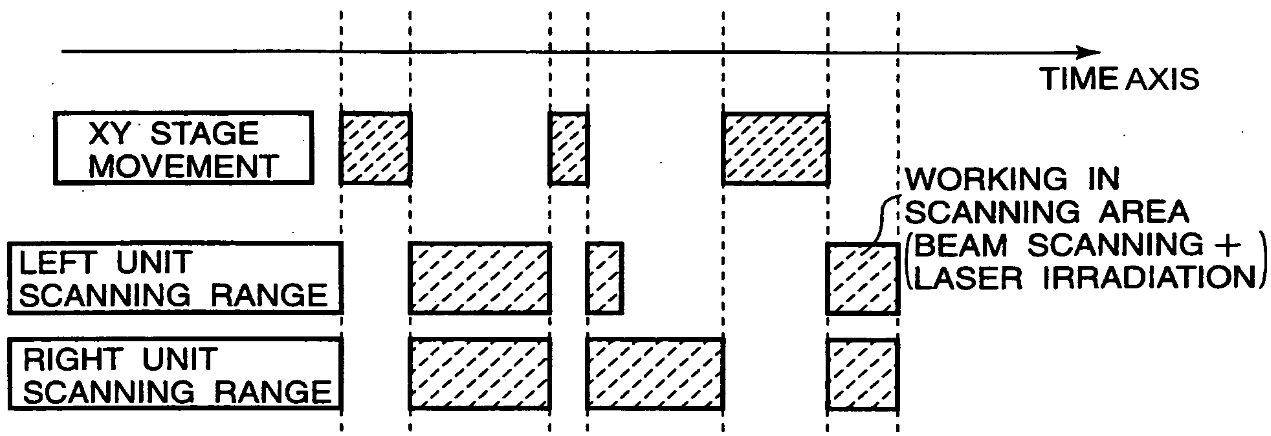

TIME AXIS
XY STAGE MOVEMENT
LEFT UNIT SCANNING RANGE
RIGHT UNIT SCANNING RANGE
WORKING IN SCANNING AREA (BEAM SCANNING + LASER IRRADIATION)

FIG.4

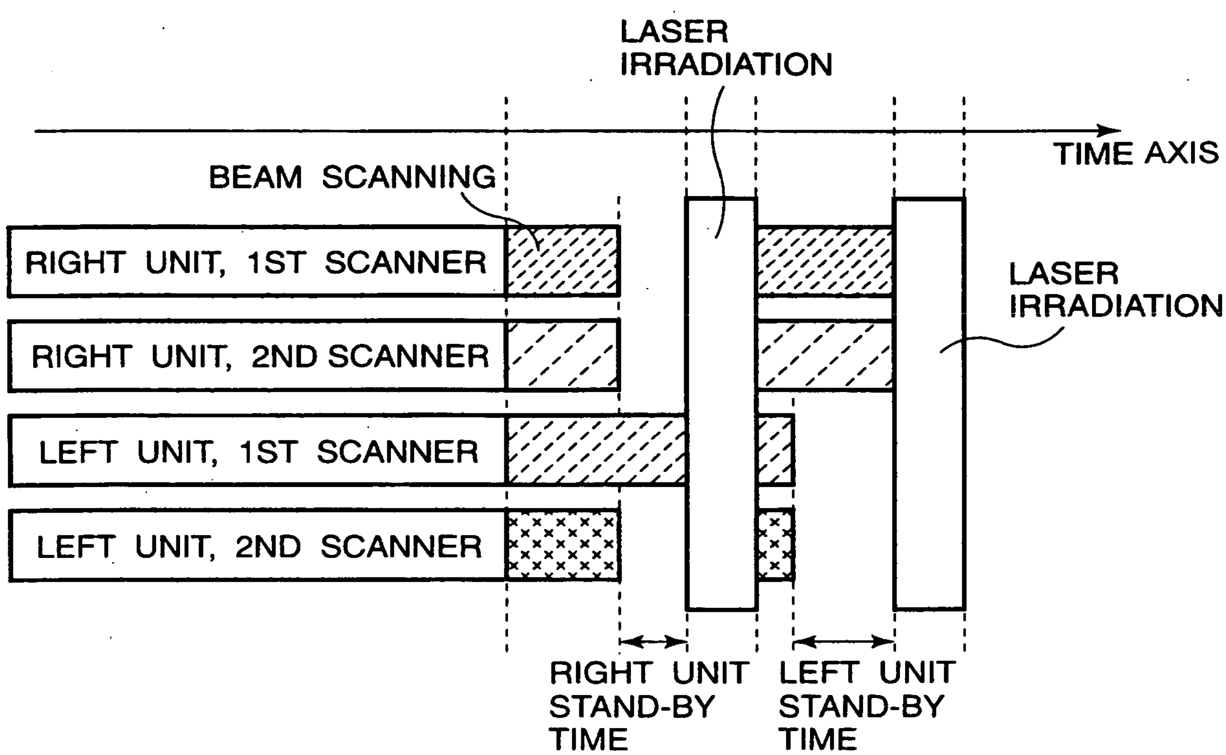

LASER IRRADIATION
TIME AXIS
BEAM SCANNING
RIGHT UNIT, 1ST SCANNER
RIGHT UNIT, 2ND SCANNER
LEFT UNIT, 1ST SCANNER
LEFT UNIT, 2ND SCANNER
LASER IRRADIATION
RIGHT UNIT STAND-BY TIME
LEFT UNIT STAND-BY TIME

FIG.5

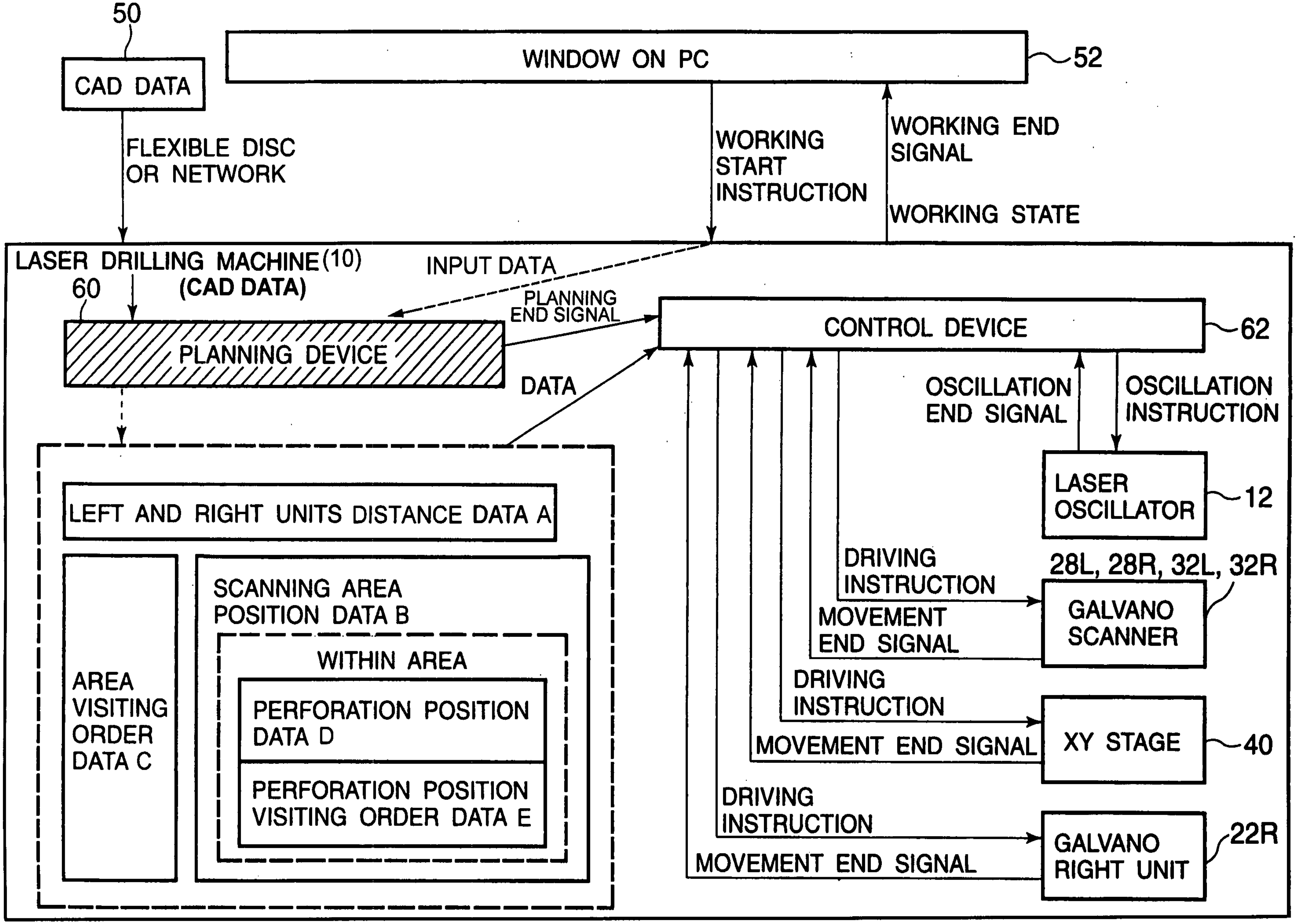

50
CAD DATA
WINDOW ON PC
52
FLEXIBLE DISC OR NETWORK
WORKING START INSTRUCTION
WORKING END SIGNAL
WORKING STATE
LASER DRILLING MACHINE (10)
(CAD DATA)
60
INPUT DATA
PLANNING END SIGNAL
PLANNING DEVICE
DATA
CONTROL DEVICE
62
OSCILLATION END SIGNAL
OSCILLATION INSTRUCTION
LASER OSCILLATOR
12
LEFT AND RIGHT UNITS DISTANCE DATA A
AREA VISITING ORDER DATA C
SCANNING AREA POSITION DATA B
WITHIN AREA
PERFORATION POSITION DATA D
PERFORATION POSITION VISITING ORDER DATA E
DRIVING INSTRUCTION
MOVEMENT END SIGNAL
28L, 28R, 32L, 32R
GALVANO SCANNER
DRIVING INSTRUCTION
MOVEMENT END SIGNAL
XY STAGE
40
DRIVING INSTRUCTION
MOVEMENT END SIGNAL
GALVANO RIGHT UNIT
22R

FIG.6

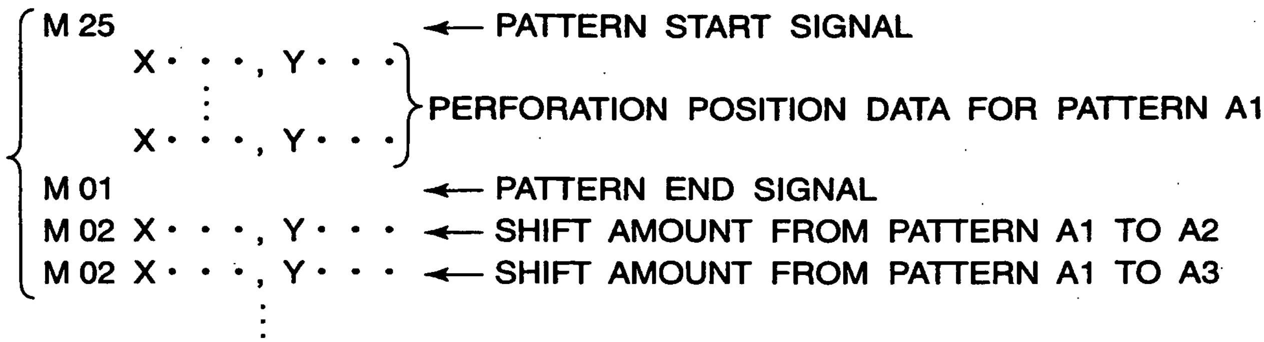

M 25
X · · ·, Y · · ·
X · · ·, Y · · ·
M 01
M 02 X · · ·, Y · · ·
M 02 X · · ·, Y · · ·
PATTERN START SIGNAL
PERFORATION POSITION DATA FOR PATTERN A1
PATTERN END SIGNAL
SHIFT AMOUNT FROM PATTERN A1 TO A2
SHIFT AMOUNT FROM PATTERN A1 TO A3

FIG.7

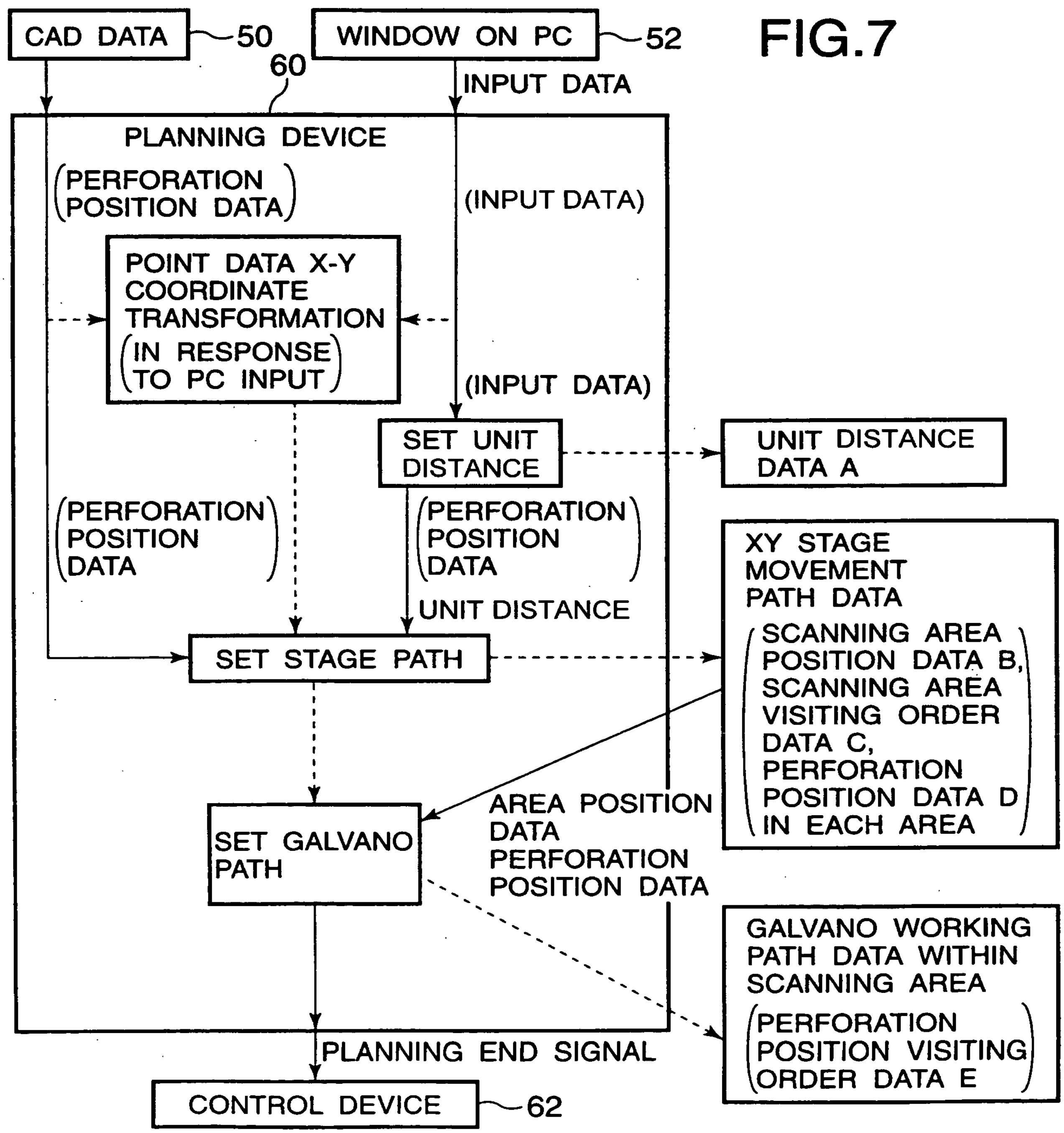

CAD DATA
50
WINDOW ON PC
52
60
INPUT DATA
PLANNING DEVICE
(PERFORATION POSITION DATA)
(INPUT DATA)
POINT DATA X-Y COORDINATE TRANSFORMATION (IN RESPONSE TO PC INPUT)
(INPUT DATA)
SET UNIT DISTANCE
UNIT DISTANCE DATA A
(PERFORATION POSITION DATA)
(PERFORATION POSITION DATA)
UNIT DISTANCE
SET STAGE PATH
XY STAGE MOVEMENT PATH DATA
(SCANNING AREA POSITION DATA B, SCANNING AREA VISITING ORDER DATA C, PERFORATION POSITION DATA D IN EACH AREA)
SET GALVANO PATH
AREA POSITION DATA
PERFORATION POSITION DATA
GALVANO WORKING PATH DATA WITHIN SCANNING AREA
(PERFORATION POSITION VISITING ORDER DATA E)
PLANNING END SIGNAL
CONTROL DEVICE
62

FIG.8

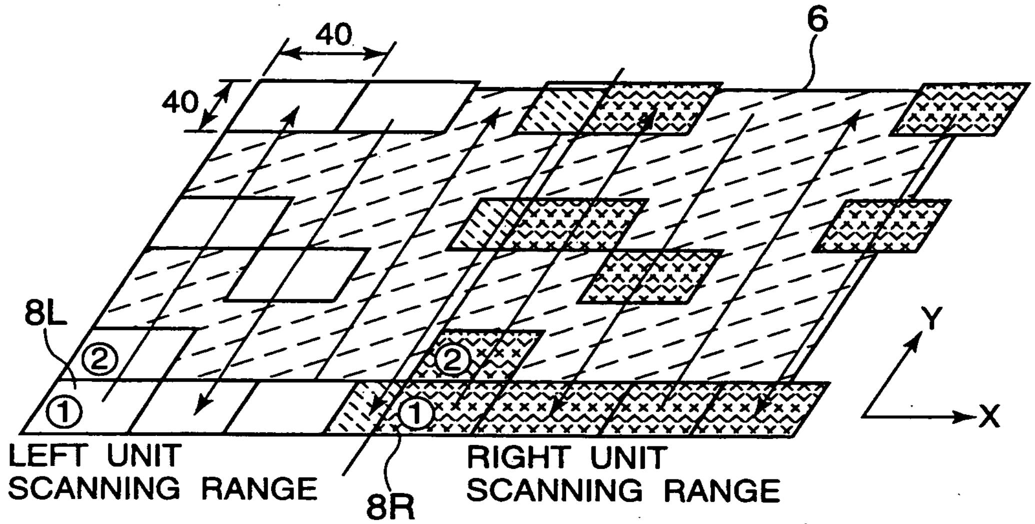

40
40
6
8L
②
①
②
①
LEFT UNIT
SCANNING RANGE
8R
RIGHT UNIT
SCANNING RANGE
Y
X

FIG.9

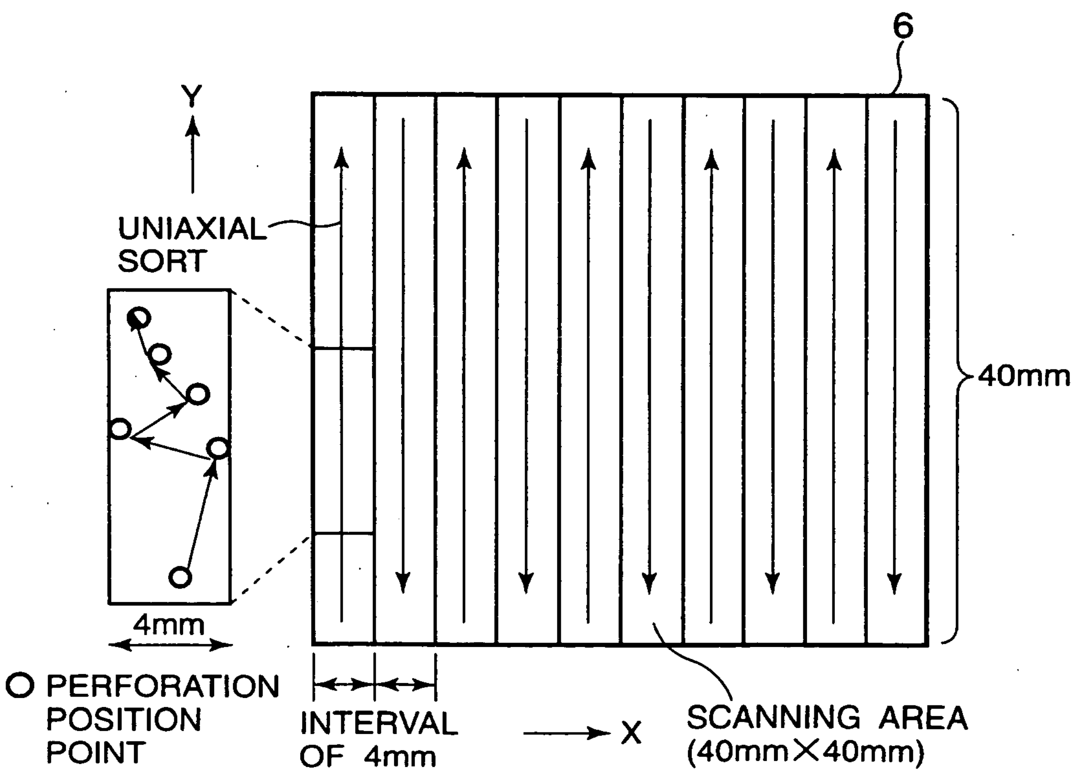

6
Y
UNIAXIAL
SORT
40mm
4mm
○ PERFORATION
POSITION
POINT
INTERVAL
OF 4mm
X
SCANNING AREA
(40mm×40mm)

FIG.10

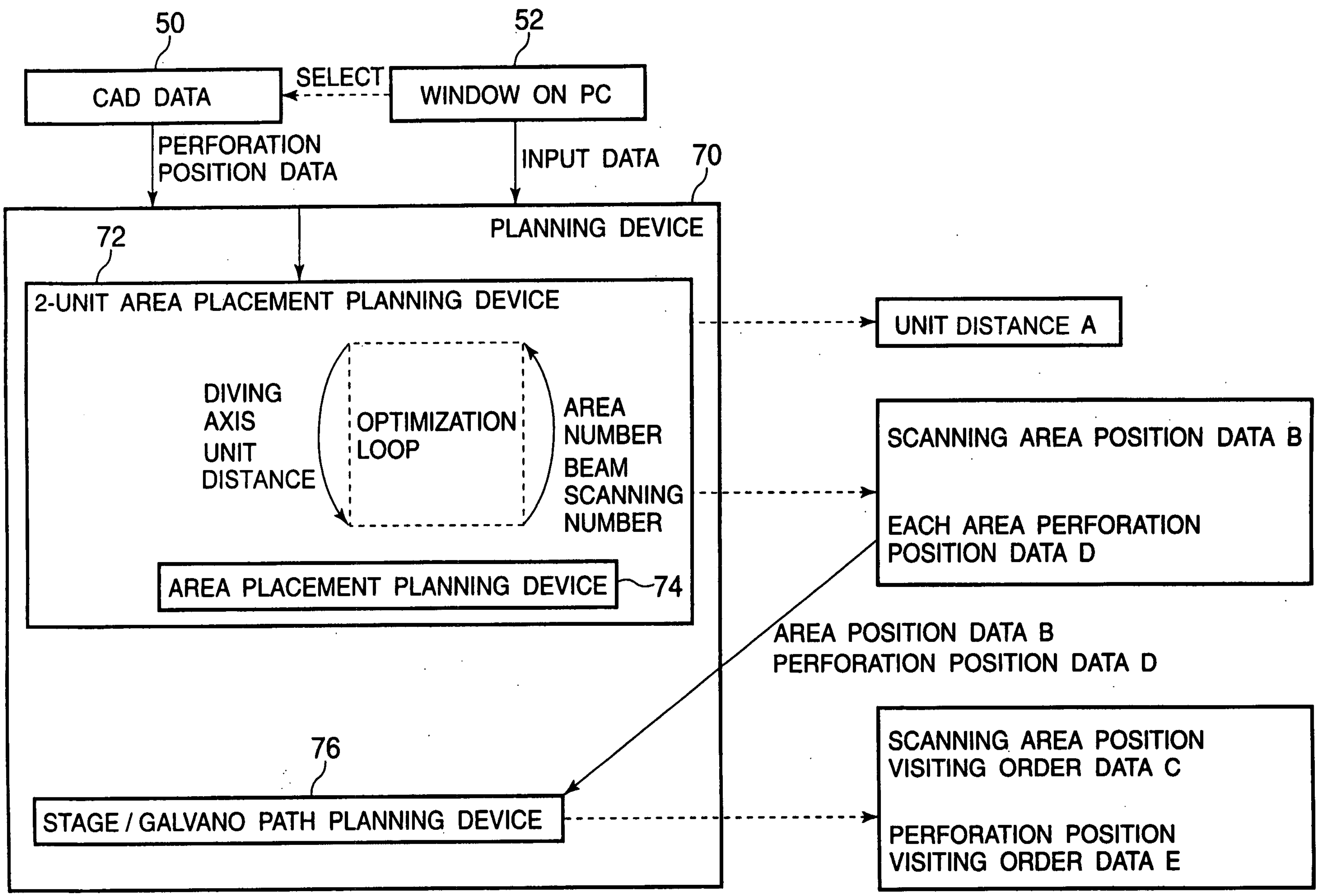

50
52
CAD DATA
SELECT
WINDOW ON PC
PERFORATION POSITION DATA
INPUT DATA
70
PLANNING DEVICE
72
2-UNIT AREA PLACEMENT PLANNING DEVICE
DIVING AXIS
UNIT DISTANCE
OPTIMIZATION LOOP
AREA NUMBER
BEAM SCANNING NUMBER
AREA PLACEMENT PLANNING DEVICE
74
76
STAGE / GALVANO PATH PLANNING DEVICE
UNIT DISTANCE A
SCANNING AREA POSITION DATA B
EACH AREA PERFORATION POSITION DATA D
AREA POSITION DATA B
PERFORATION POSITION DATA D
SCANNING AREA POSITION VISITING ORDER DATA C
PERFORATION POSITION VISITING ORDER DATA E

FIG.11

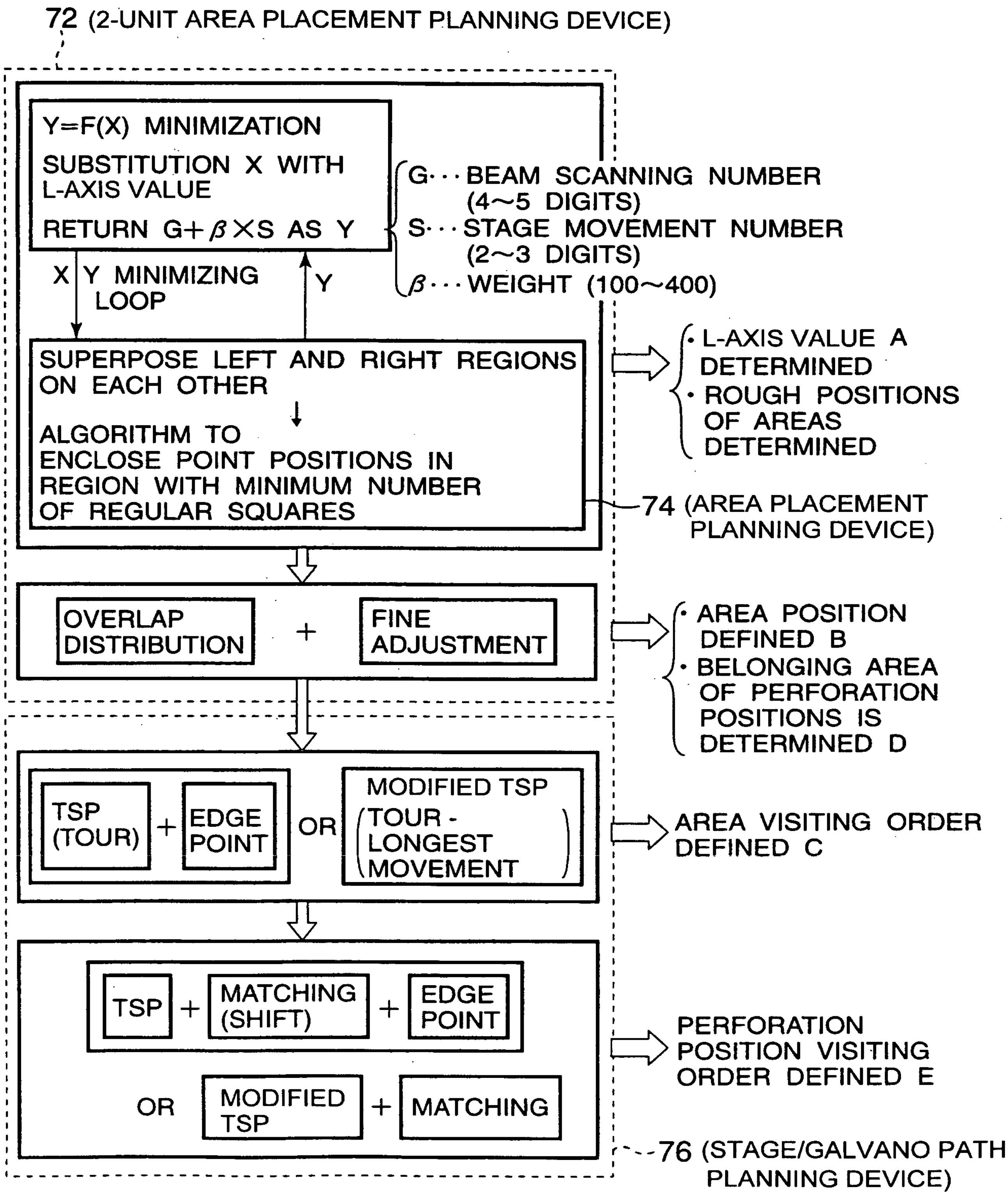

72 (2-UNIT AREA PLACEMENT PLANNING DEVICE)
Y=F(X) MINIMIZATION
SUBSTITUTION X WITH L-AXIS VALUE
RETURN G+β×S AS Y
G···BEAM SCANNING NUMBER (4~5 DIGITS)
S···STAGE MOVEMENT NUMBER (2~3 DIGITS)
β···WEIGHT (100~400)
X
Y MINIMIZING LOOP
Y
SUPERPOSE LEFT AND RIGHT REGIONS ON EACH OTHER
ALGORITHM TO ENCLOSE POINT POSITIONS IN REGION WITH MINIMUM NUMBER OF REGULAR SQUARES
• L-AXIS VALUE A DETERMINED
• ROUGH POSITIONS OF AREAS DETERMINED
74 (AREA PLACEMENT PLANNING DEVICE)
OVERLAP DISTRIBUTION
+
FINE ADJUSTMENT
• AREA POSITION DEFINED B
• BELONGING AREA OF PERFORATION POSITIONS IS DETERMINED D
TSP (TOUR)
+
EDGE POINT
OR
MODIFIED TSP
(TOUR - LONGEST MOVEMENT)
AREA VISITING ORDER DEFINED C
TSP
+
MATCHING (SHIFT)
+
EDGE POINT
OR
MODIFIED TSP
+
MATCHING
PERFORATION POSITION VISITING ORDER DEFINED E
76 (STAGE/GALVANO PATH PLANNING DEVICE)

FIG.12

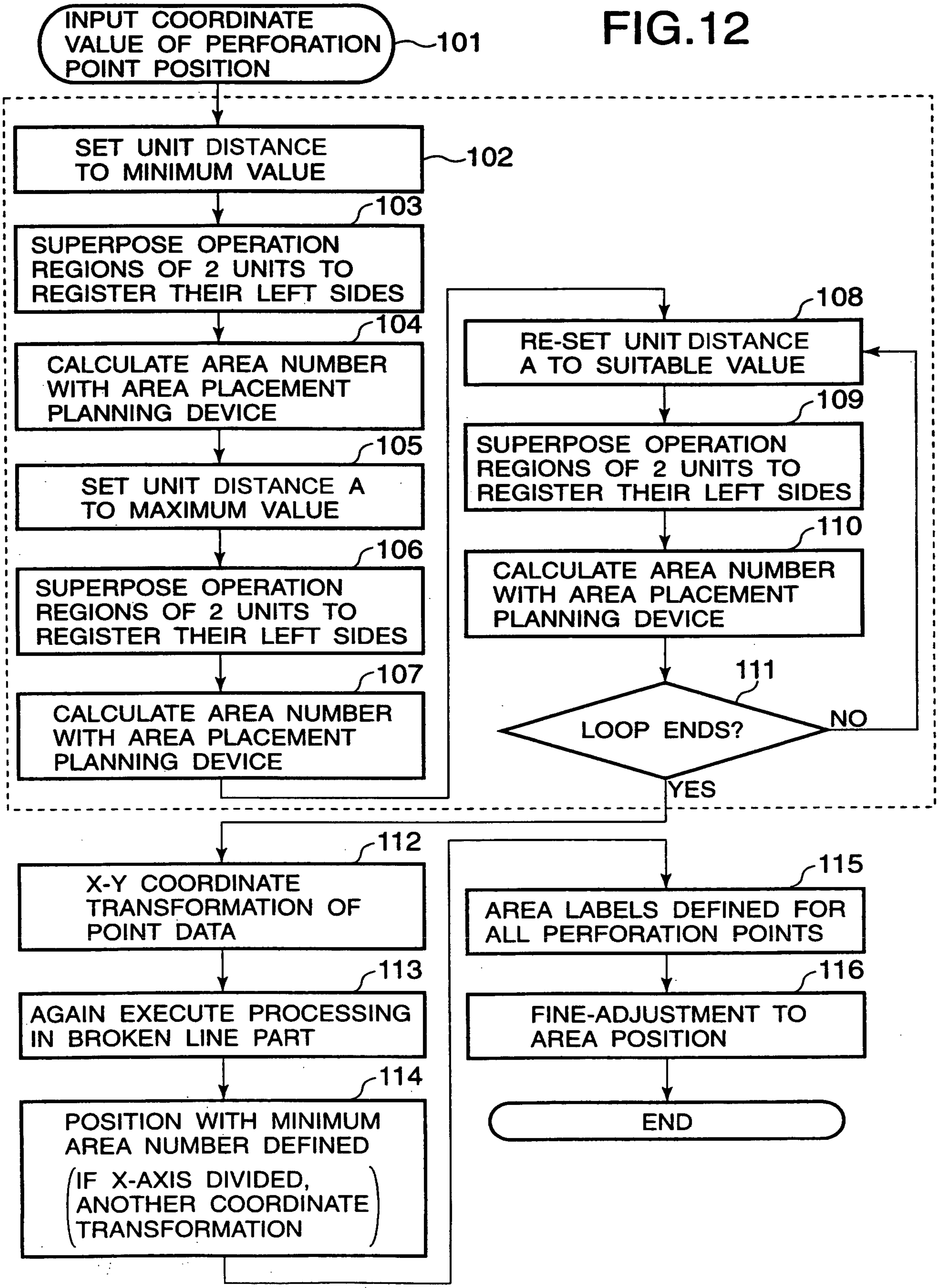

INPUT COORDINATE VALUE OF PERFORATION POINT POSITION
101
SET UNIT DISTANCE TO MINIMUM VALUE
102
103
SUPERPOSE OPERATION REGIONS OF 2 UNITS TO REGISTER THEIR LEFT SIDES
104
CALCULATE AREA NUMBER WITH AREA PLACEMENT PLANNING DEVICE
105
SET UNIT DISTANCE A TO MAXIMUM VALUE
106
SUPERPOSE OPERATION REGIONS OF 2 UNITS TO REGISTER THEIR LEFT SIDES
107
CALCULATE AREA NUMBER WITH AREA PLACEMENT PLANNING DEVICE
108
RE-SET UNIT DISTANCE A TO SUITABLE VALUE
109
SUPERPOSE OPERATION REGIONS OF 2 UNITS TO REGISTER THEIR LEFT SIDES
110
CALCULATE AREA NUMBER WITH AREA PLACEMENT PLANNING DEVICE
111
LOOP ENDS?
NO
YES
112
X-Y COORDINATE TRANSFORMATION OF POINT DATA
113
AGAIN EXECUTE PROCESSING IN BROKEN LINE PART
114
POSITION WITH MINIMUM AREA NUMBER DEFINED
(IF X-AXIS DIVIDED, ANOTHER COORDINATE TRANSFORMATION)
115
AREA LABELS DEFINED FOR ALL PERFORATION POINTS
116
FINE-ADJUSTMENT TO AREA POSITION
END

FIG.13

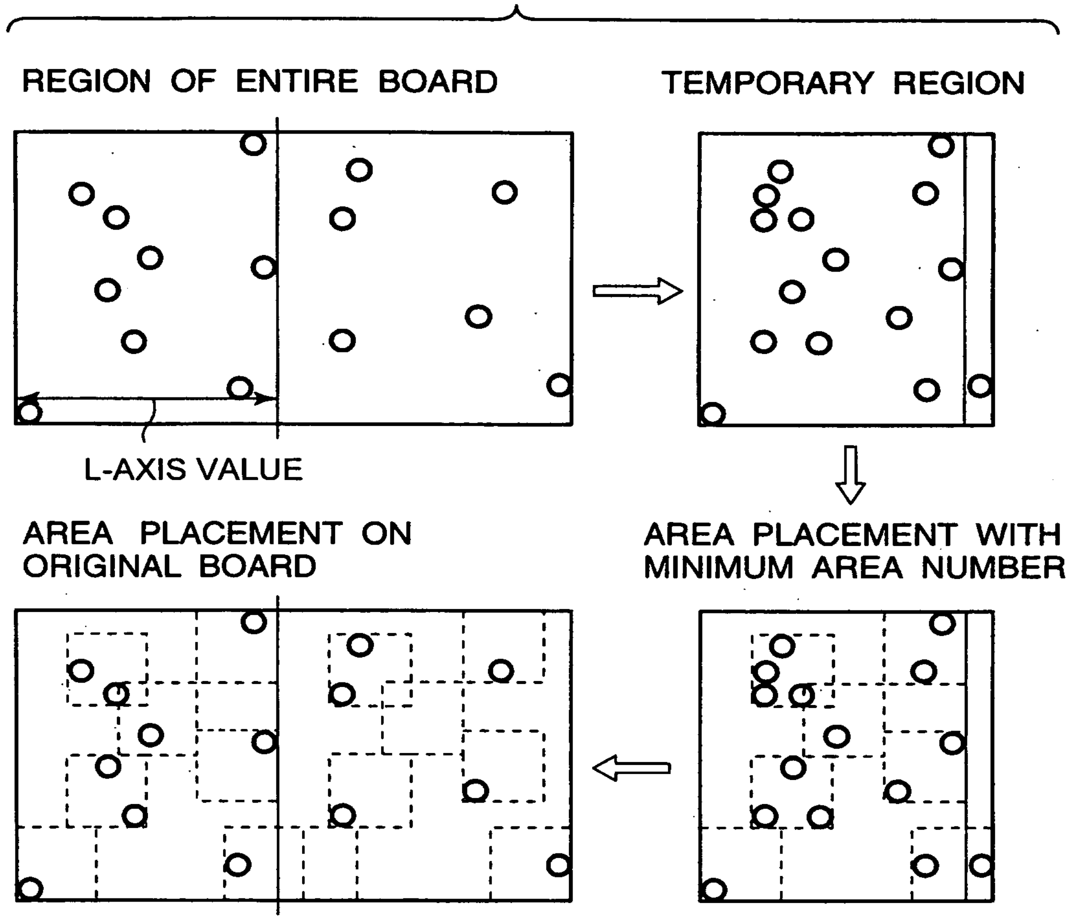

REGION OF ENTIRE BOARD
TEMPORARY REGION
L-AXIS VALUE
AREA PLACEMENT ON ORIGINAL BOARD
AREA PLACEMENT WITH MINIMUM AREA NUMBER

FIG.14

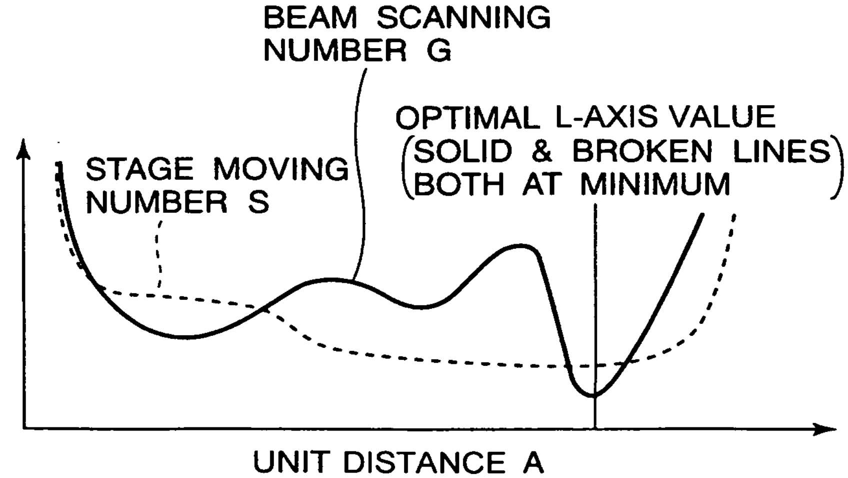

BEAM SCANNING NUMBER G
OPTIMAL L-AXIS VALUE (SOLID & BROKEN LINES BOTH AT MINIMUM)
STAGE MOVING NUMBER S
UNIT DISTANCE A

FIG.15

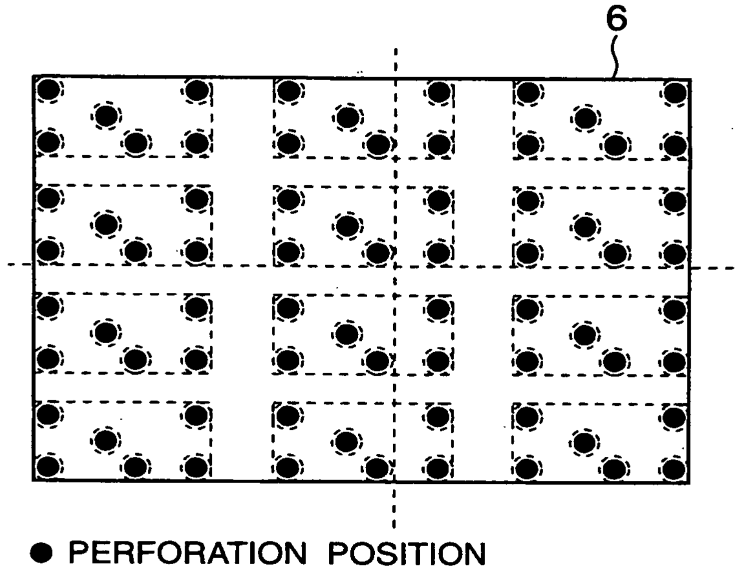

6
PERFORATION POSITION

FIG.16

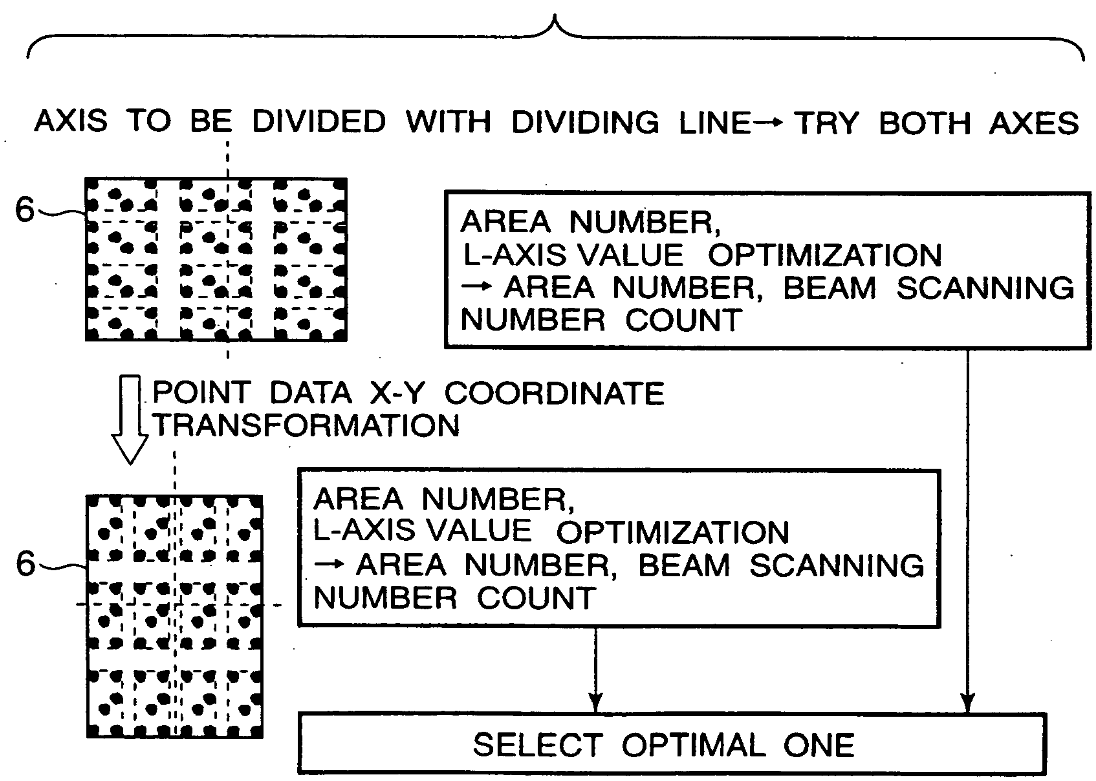

AXIS TO BE DIVIDED WITH DIVIDING LINE→ TRY BOTH AXES
6
AREA NUMBER, L-AXIS VALUE OPTIMIZATION → AREA NUMBER, BEAM SCANNING NUMBER COUNT
POINT DATA X-Y COORDINATE TRANSFORMATION
6
AREA NUMBER, L-AXIS VALUE OPTIMIZATION → AREA NUMBER, BEAM SCANNING NUMBER COUNT
SELECT OPTIMAL ONE

FIG.17

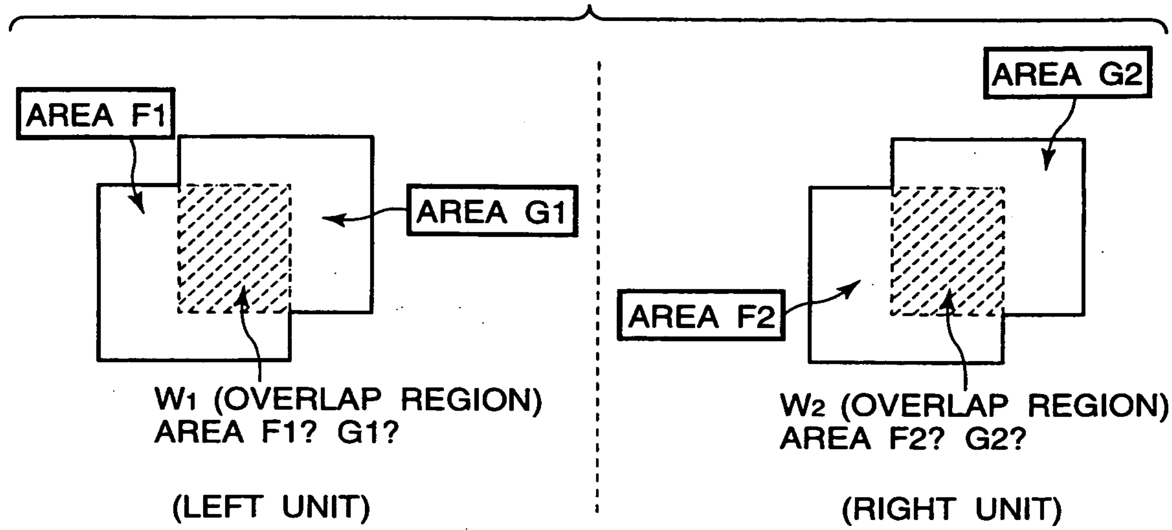

AREA F1
AREA G1
W1 (OVERLAP REGION)
AREA F1? G1?
(LEFT UNIT)
AREA G2
AREA F2
W2 (OVERLAP REGION)
AREA F2? G2?
(RIGHT UNIT)

FIG.18

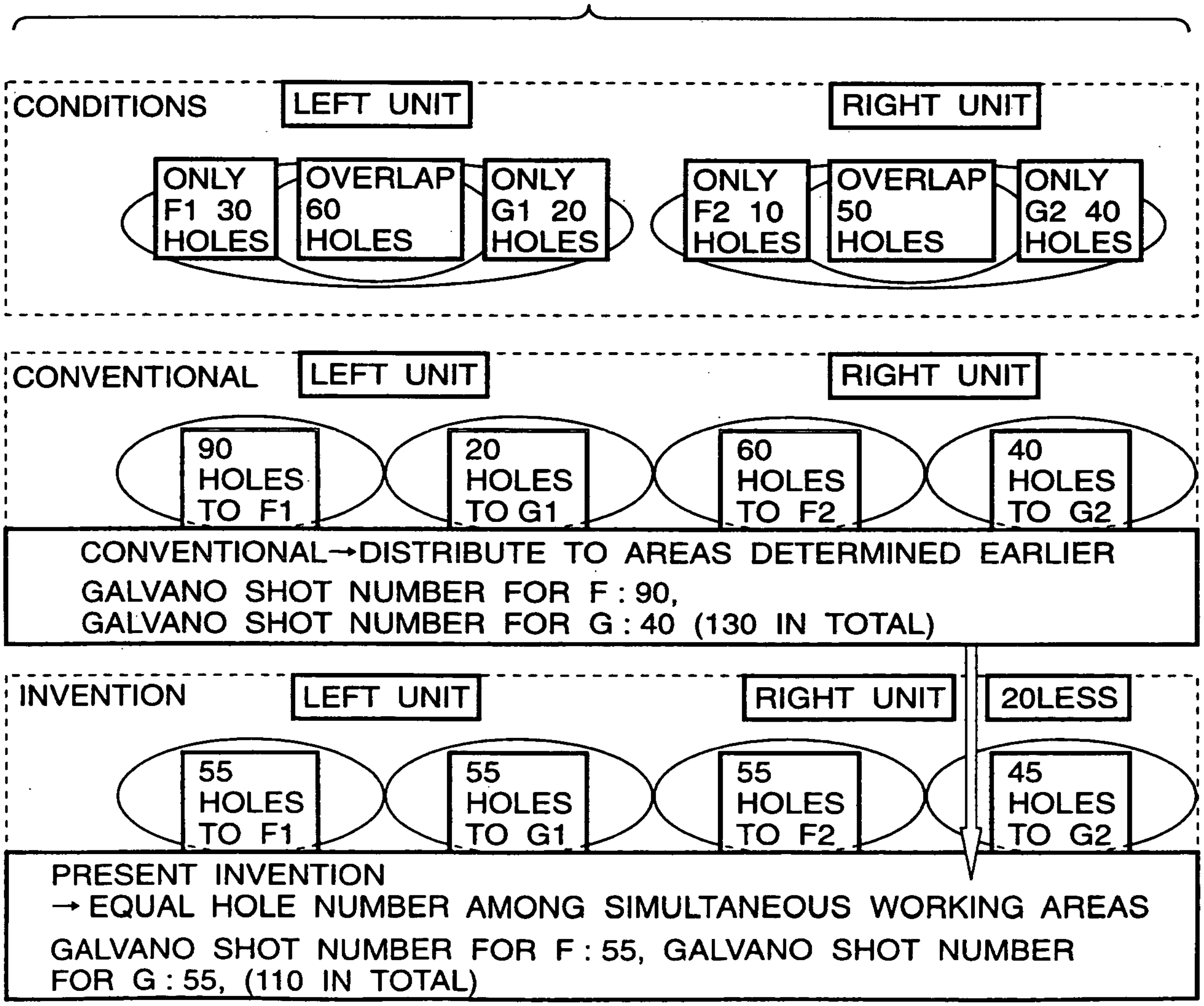

CONDITIONS
LEFT UNIT
RIGHT UNIT
ONLY F1 30 HOLES
OVERLAP 60 HOLES
ONLY G1 20 HOLES
ONLY F2 10 HOLES
OVERLAP 50 HOLES
ONLY G2 40 HOLES
CONVENTIONAL
LEFT UNIT
RIGHT UNIT
90 HOLES TO F1
20 HOLES TO G1
60 HOLES TO F2
40 HOLES TO G2
CONVENTIONAL→DISTRIBUTE TO AREAS DETERMINED EARLIER
GALVANO SHOT NUMBER FOR F : 90,
GALVANO SHOT NUMBER FOR G : 40 (130 IN TOTAL)
INVENTION
LEFT UNIT
RIGHT UNIT
20LESS
55 HOLES TO F1
55 HOLES TO G1
55 HOLES TO F2
45 HOLES TO G2
PRESENT INVENTION
→EQUAL HOLE NUMBER AMONG SIMULTANEOUS WORKING AREAS
GALVANO SHOT NUMBER FOR F : 55, GALVANO SHOT NUMBER
FOR G : 55, (110 IN TOTAL)

FIG.19

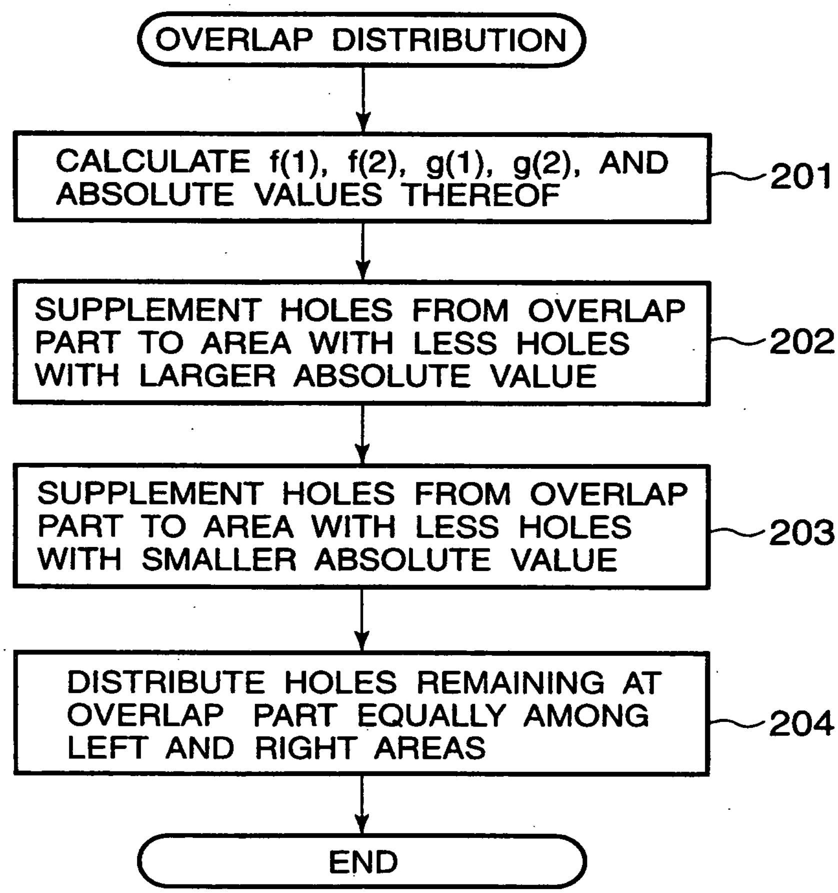

OVERLAP DISTRIBUTION
CALCULATE f(1), f(2), g(1), g(2), AND ABSOLUTE VALUES THEREOF
201
SUPPLEMENT HOLES FROM OVERLAP PART TO AREA WITH LESS HOLES WITH LARGER ABSOLUTE VALUE
202
SUPPLEMENT HOLES FROM OVERLAP PART TO AREA WITH LESS HOLES WITH SMALLER ABSOLUTE VALUE
203
DISTRIBUTE HOLES REMAINING AT OVERLAP PART EQUALLY AMONG LEFT AND RIGHT AREAS
204
END

FIG.20

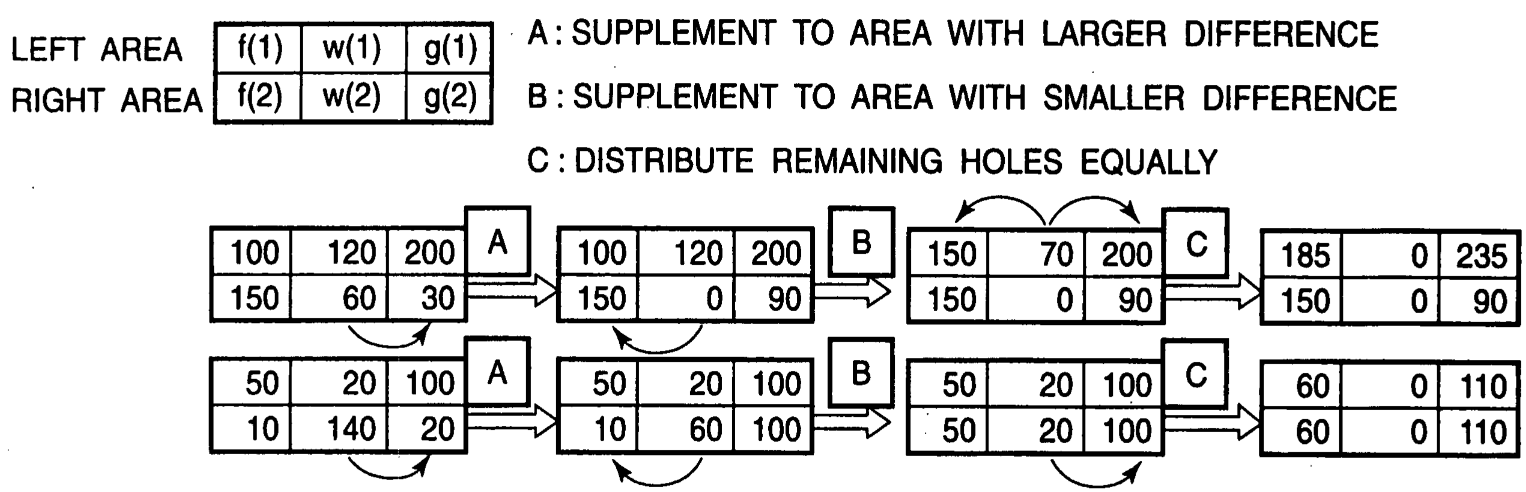

LEFT AREA
RIGHT AREA
f(1) w(1) g(1)
f(2) w(2) g(2)
A : SUPPLEMENT TO AREA WITH LARGER DIFFERENCE
B : SUPPLEMENT TO AREA WITH SMALLER DIFFERENCE
C : DISTRIBUTE REMAINING HOLES EQUALLY
100 120 200
150 60 30
A
100 120 200
150 0 90
B
150 70 200
150 0 90
C
185 0 235
150 0 90
50 20 100
10 140 20
A
50 20 100
10 60 100
B
50 20 100
50 20 100
C
60 0 110
60 0 110

FIG.21

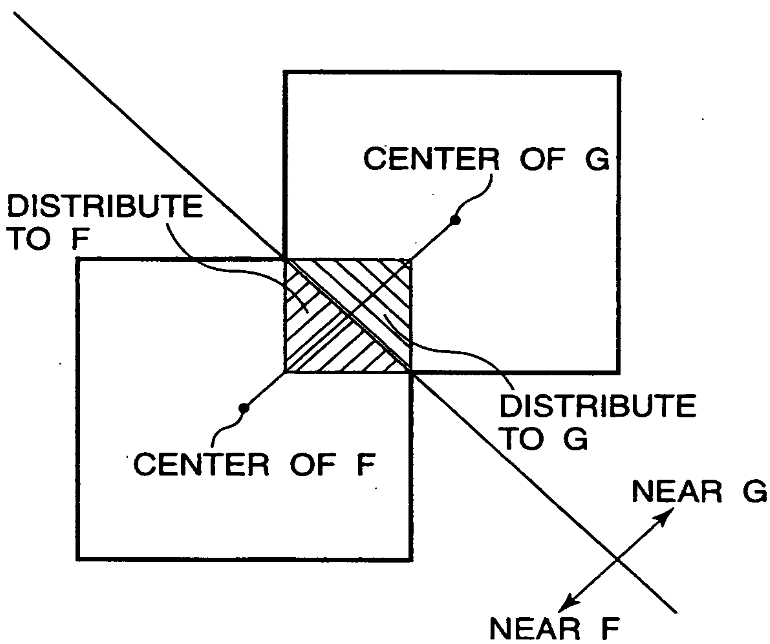

CENTER OF G
DISTRIBUTE TO F
DISTRIBUTE TO G
CENTER OF F
NEAR G
NEAR F

FIG.22

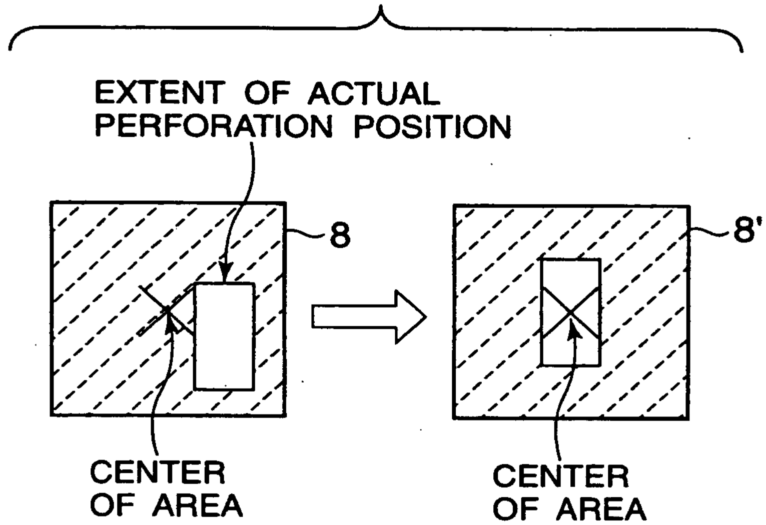

EXTENT OF ACTUAL PERFORATION POSITION
8
8'
CENTER OF AREA
CENTER OF AREA

FIG.23

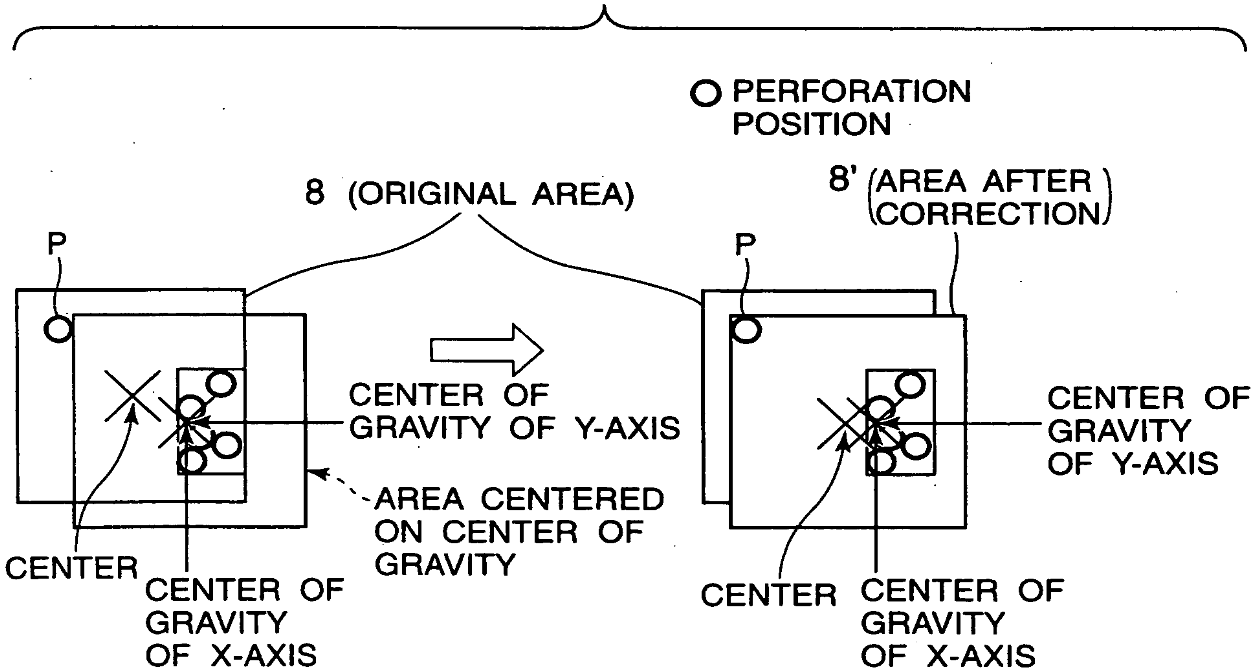

O PERFORATION POSITION
8 (ORIGINAL AREA)
8' (AREA AFTER CORRECTION)
P
P
CENTER OF GRAVITY OF Y-AXIS
AREA CENTERED ON CENTER OF GRAVITY
CENTER
CENTER OF GRAVITY OF X-AXIS
CENTER OF GRAVITY OF Y-AXIS
CENTER
CENTER OF GRAVITY OF X-AXIS

FIG.24

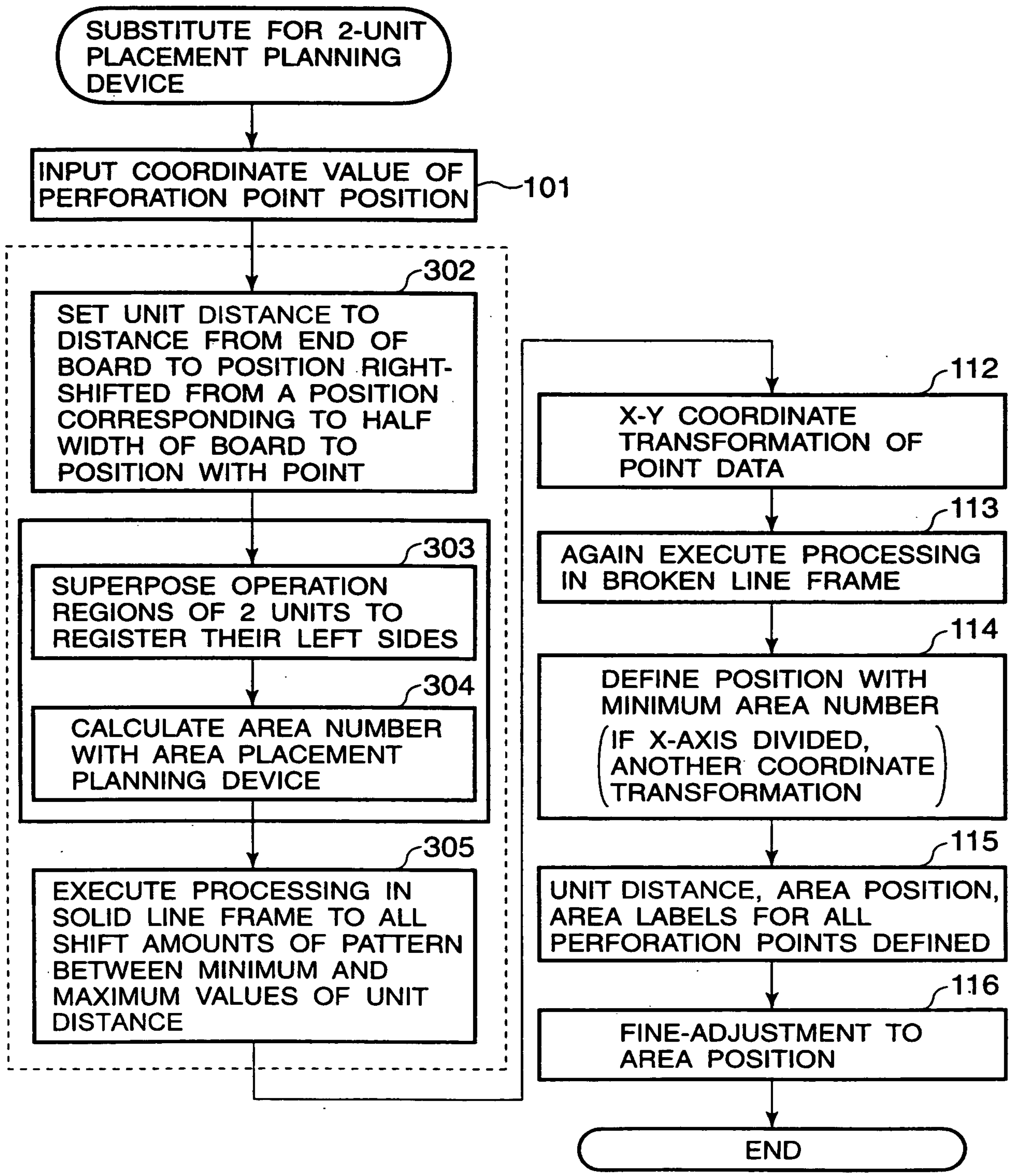

SUBSTITUTE FOR 2-UNIT PLACEMENT PLANNING DEVICE
INPUT COORDINATE VALUE OF PERFORATION POINT POSITION
101
302
SET UNIT DISTANCE TO DISTANCE FROM END OF BOARD TO POSITION RIGHT-SHIFTED FROM A POSITION CORRESPONDING TO HALF WIDTH OF BOARD TO POSITION WITH POINT
303
SUPERPOSE OPERATION REGIONS OF 2 UNITS TO REGISTER THEIR LEFT SIDES
304
CALCULATE AREA NUMBER WITH AREA PLACEMENT PLANNING DEVICE
305
EXECUTE PROCESSING IN SOLID LINE FRAME TO ALL SHIFT AMOUNTS OF PATTERN BETWEEN MINIMUM AND MAXIMUM VALUES OF UNIT DISTANCE
112
X-Y COORDINATE TRANSFORMATION OF POINT DATA
113
AGAIN EXECUTE PROCESSING IN BROKEN LINE FRAME
114
DEFINE POSITION WITH MINIMUM AREA NUMBER
(IF X-AXIS DIVIDED, ANOTHER COORDINATE TRANSFORMATION)
115
UNIT DISTANCE, AREA POSITION, AREA LABELS FOR ALL PERFORATION POINTS DEFINED
116
FINE-ADJUSTMENT TO AREA POSITION
END

FIG.25

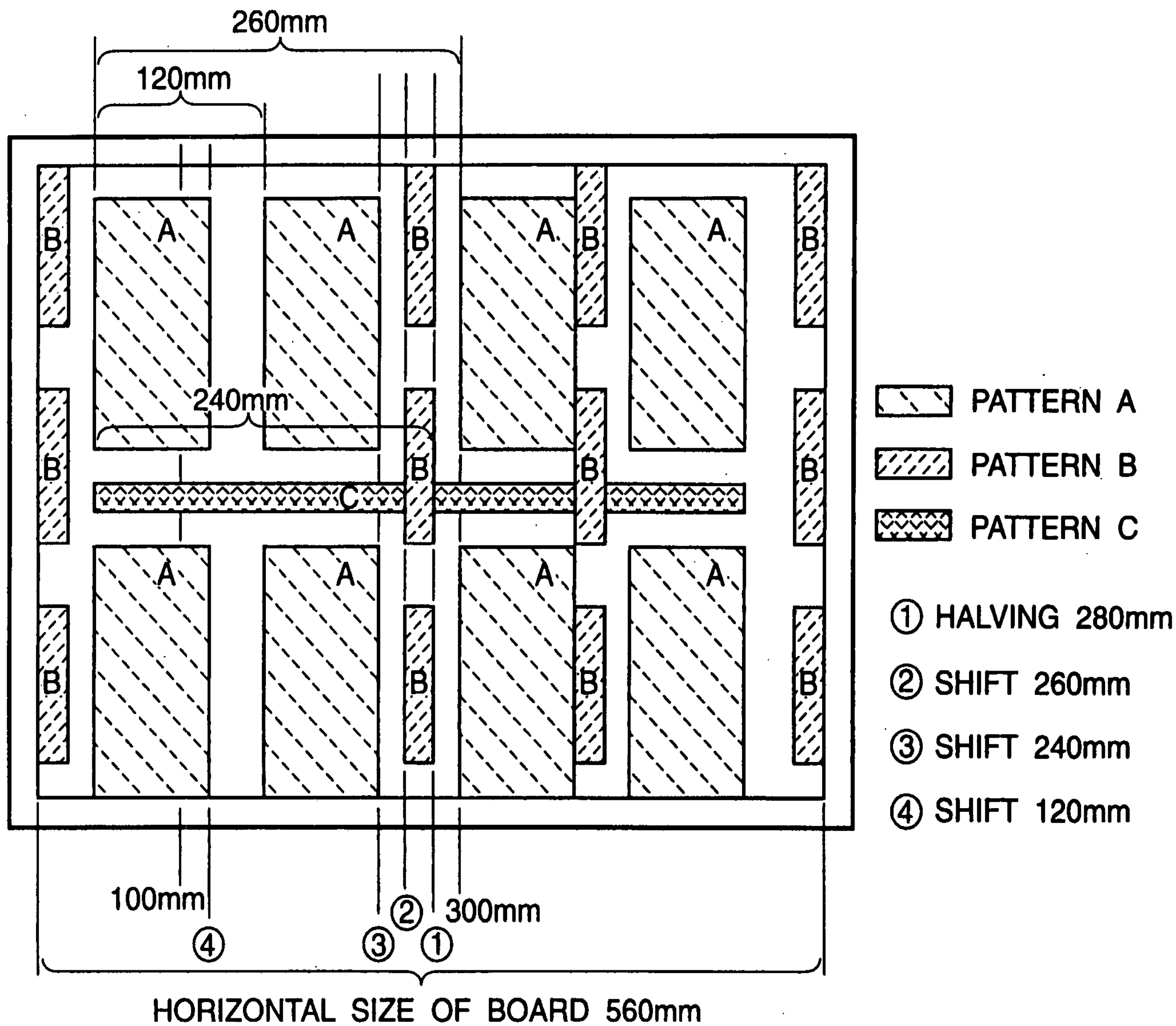

260mm
120mm
240mm
A
B
C
PATTERN A
PATTERN B
PATTERN C
① HALVING 280mm
② SHIFT 260mm
③ SHIFT 240mm
④ SHIFT 120mm
100mm
300mm
HORIZONTAL SIZE OF BOARD 560mm

FIG.26

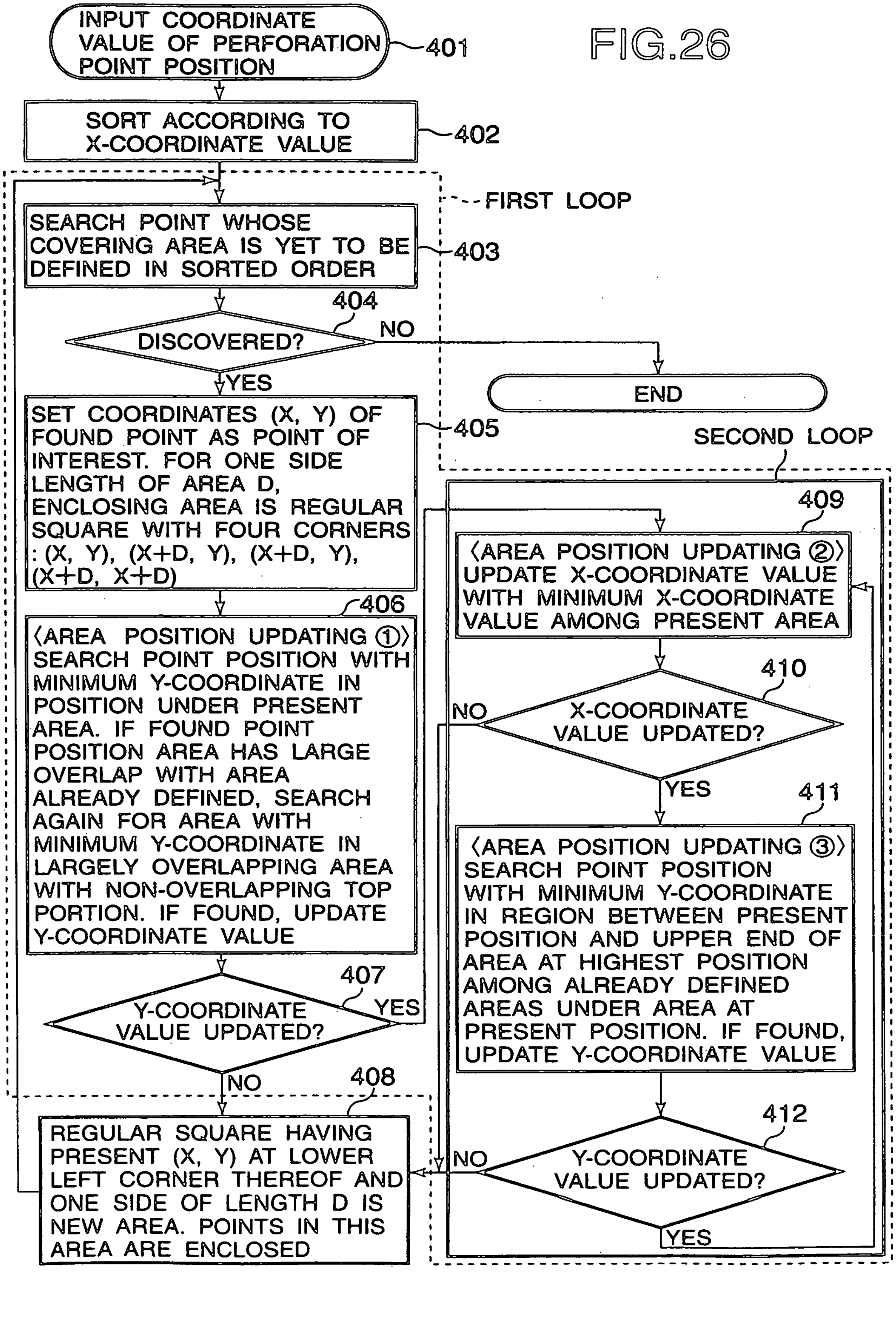

INPUT COORDINATE VALUE OF PERFORATION POINT POSITION
401
SORT ACCORDING TO X-COORDINATE VALUE
402
FIRST LOOP
SEARCH POINT WHOSE COVERING AREA IS YET TO BE DEFINED IN SORTED ORDER
403
404
DISCOVERED?
NO
END
YES
SET COORDINATES (X, Y) OF FOUND POINT AS POINT OF INTEREST. FOR ONE SIDE LENGTH OF AREA D, ENCLOSING AREA IS REGULAR SQUARE WITH FOUR CORNERS : (X, Y), (X+D, Y), (X+D, Y), (X+D, X+D)
405
SECOND LOOP
406
⟨AREA POSITION UPDATING ①⟩ SEARCH POINT POSITION WITH MINIMUM Y-COORDINATE IN POSITION UNDER PRESENT AREA. IF FOUND POINT POSITION AREA HAS LARGE OVERLAP WITH AREA ALREADY DEFINED, SEARCH AGAIN FOR AREA WITH MINIMUM Y-COORDINATE IN LARGELY OVERLAPPING AREA WITH NON-OVERLAPPING TOP PORTION. IF FOUND, UPDATE Y-COORDINATE VALUE
407
Y-COORDINATE VALUE UPDATED?
YES
NO
408
REGULAR SQUARE HAVING PRESENT (X, Y) AT LOWER LEFT CORNER THEREOF AND ONE SIDE OF LENGTH D IS NEW AREA. POINTS IN THIS AREA ARE ENCLOSED
409
⟨AREA POSITION UPDATING ②⟩ UPDATE X-COORDINATE VALUE WITH MINIMUM X-COORDINATE VALUE AMONG PRESENT AREA
410
X-COORDINATE VALUE UPDATED?
NO
YES
411
⟨AREA POSITION UPDATING ③⟩ SEARCH POINT POSITION WITH MINIMUM Y-COORDINATE IN REGION BETWEEN PRESENT POSITION AND UPPER END OF AREA AT HIGHEST POSITION AMONG ALREADY DEFINED AREAS UNDER AREA AT PRESENT POSITION. IF FOUND, UPDATE Y-COORDINATE VALUE
412
Y-COORDINATE VALUE UPDATED?
NO
YES

FIG.27

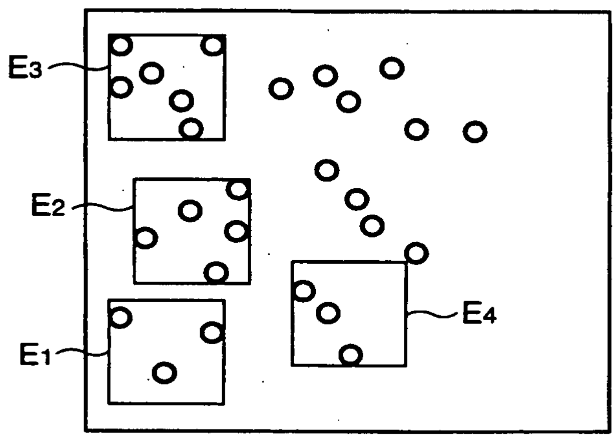


FIG.28

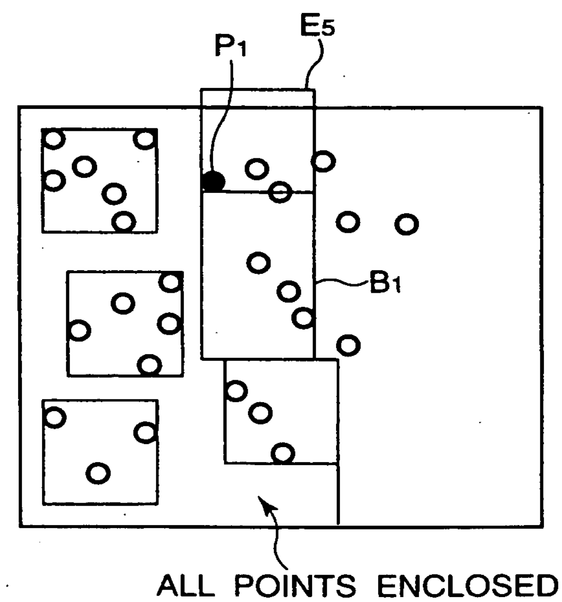


FIG.29

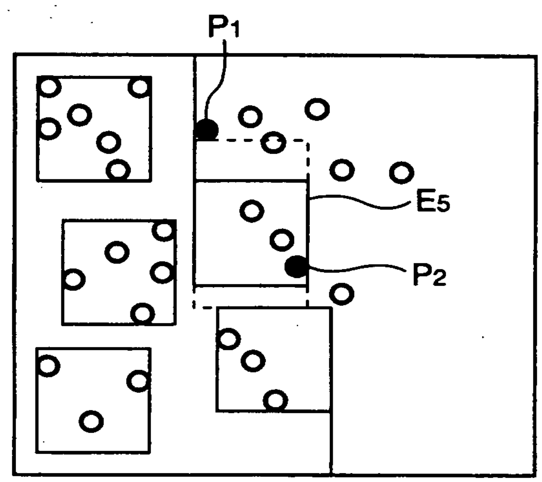

P1
E5
P2

FIG.30

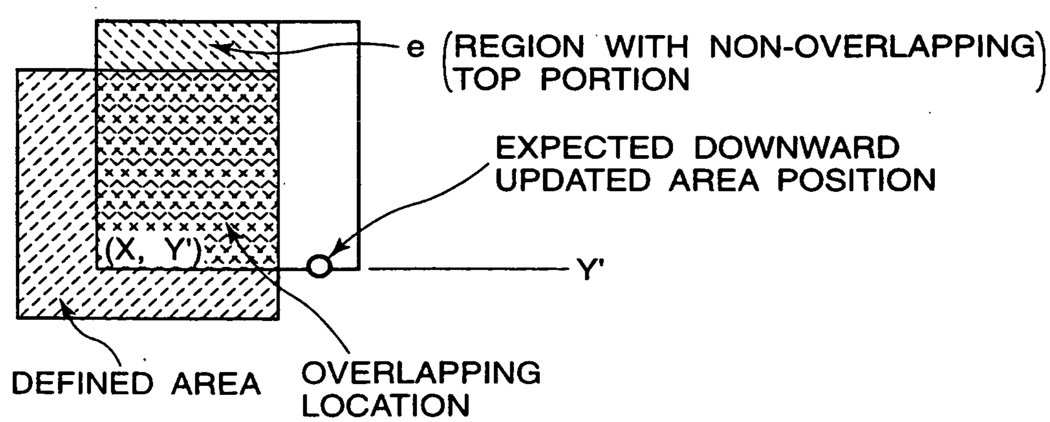

e (REGION WITH NON-OVERLAPPING TOP PORTION)
EXPECTED DOWNWARD UPDATED AREA POSITION
(X, Y')
Y'
DEFINED AREA
OVERLAPPING LOCATION

FIG.31

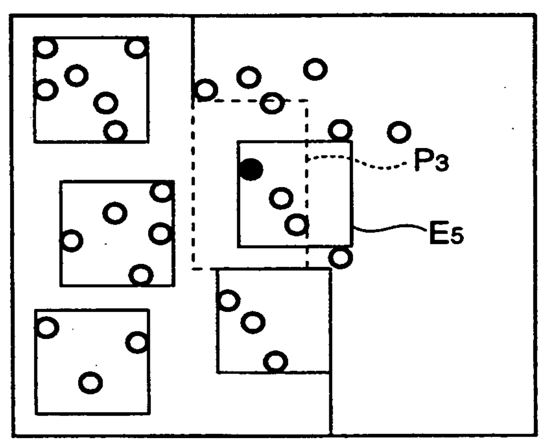

P3
E5

FIG.32

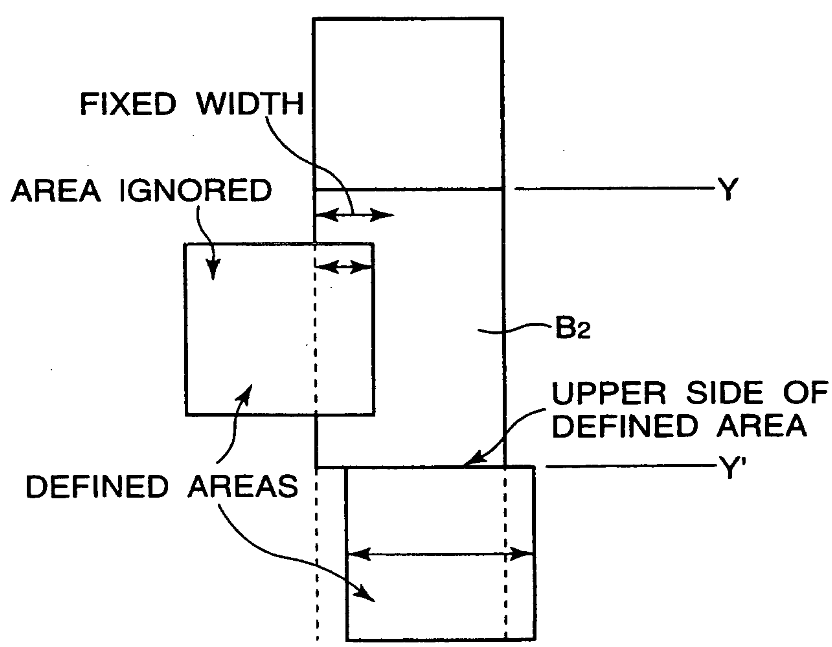

FIXED WIDTH
AREA IGNORED
Y
B2
UPPER SIDE OF DEFINED AREA
Y'
DEFINED AREAS

FIG.33

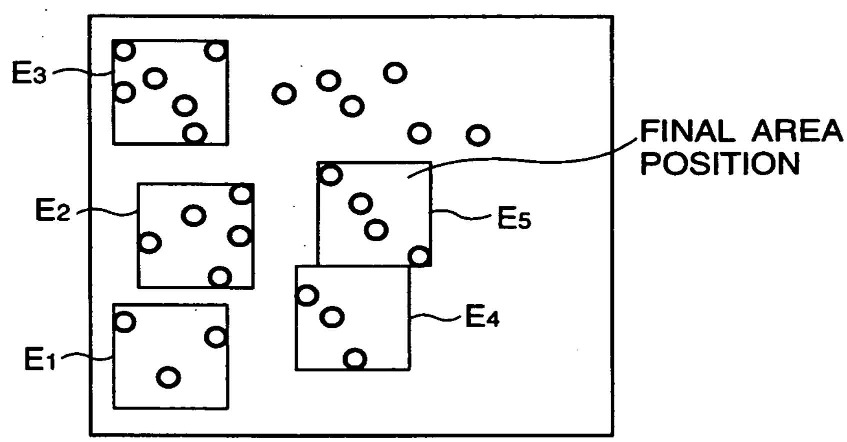


FIG.34A

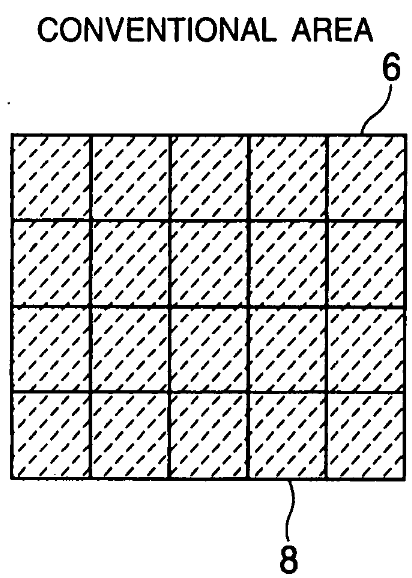


FIG.34B

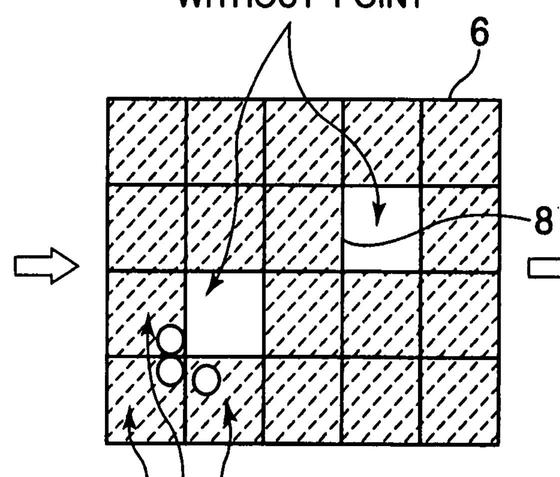


FIG.34C

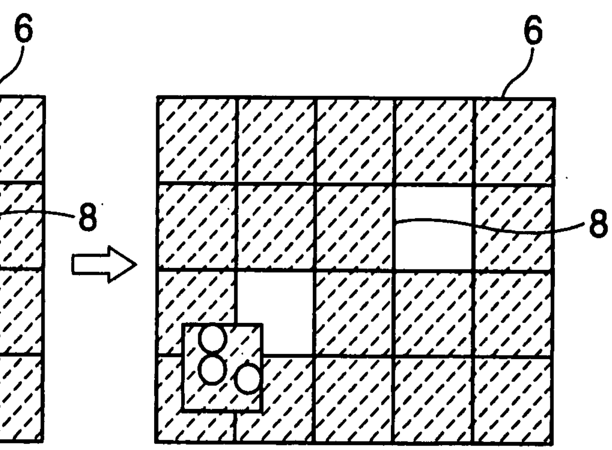


FIG.35

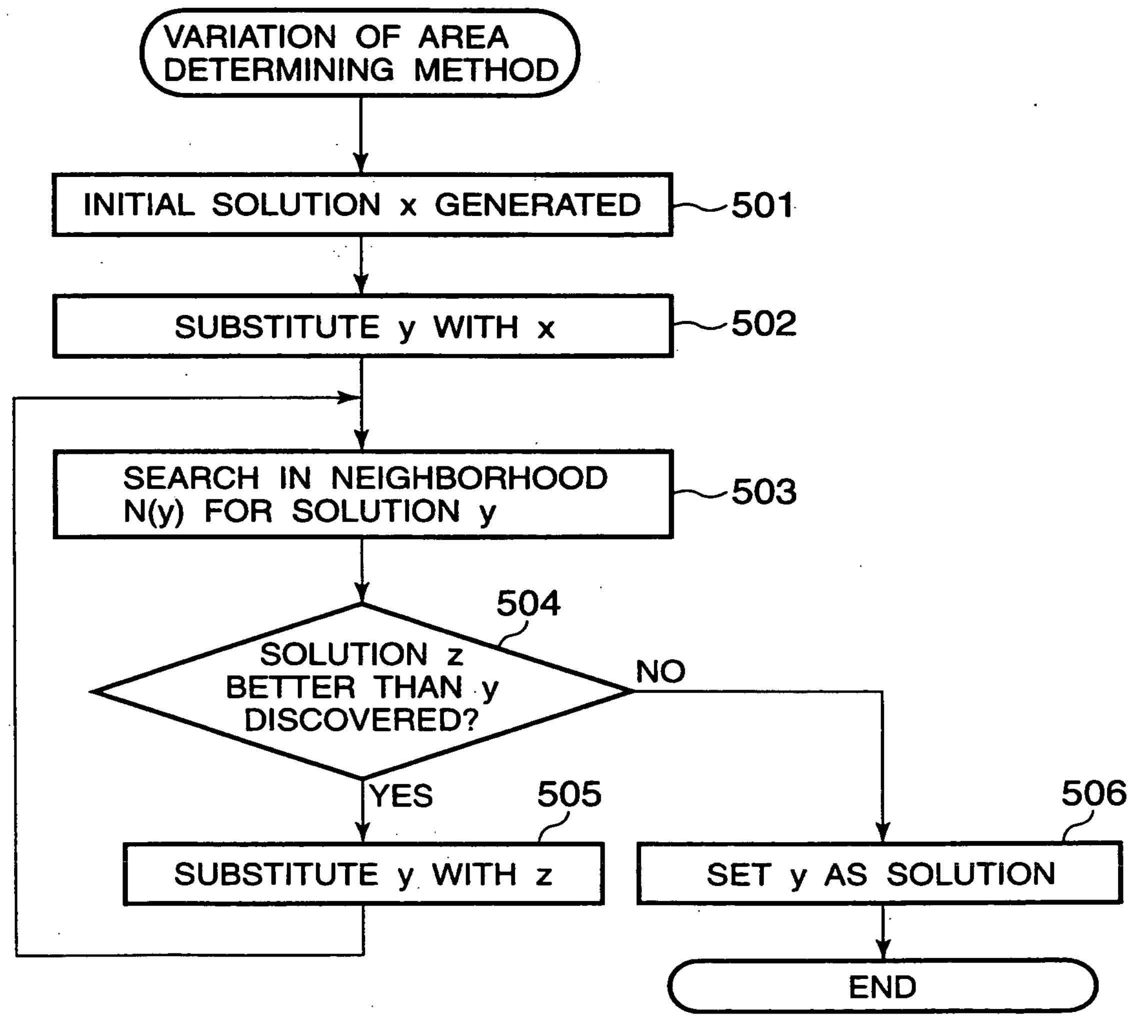

VARIATION OF AREA DETERMINING METHOD
INITIAL SOLUTION x GENERATED
501
SUBSTITUTE y WITH x
502
SEARCH IN NEIGHBORHOOD N(y) FOR SOLUTION y
503
504
SOLUTION z BETTER THAN y DISCOVERED?
NO
YES
505
506
SUBSTITUTE y WITH z
SET y AS SOLUTION
END

FIG.36

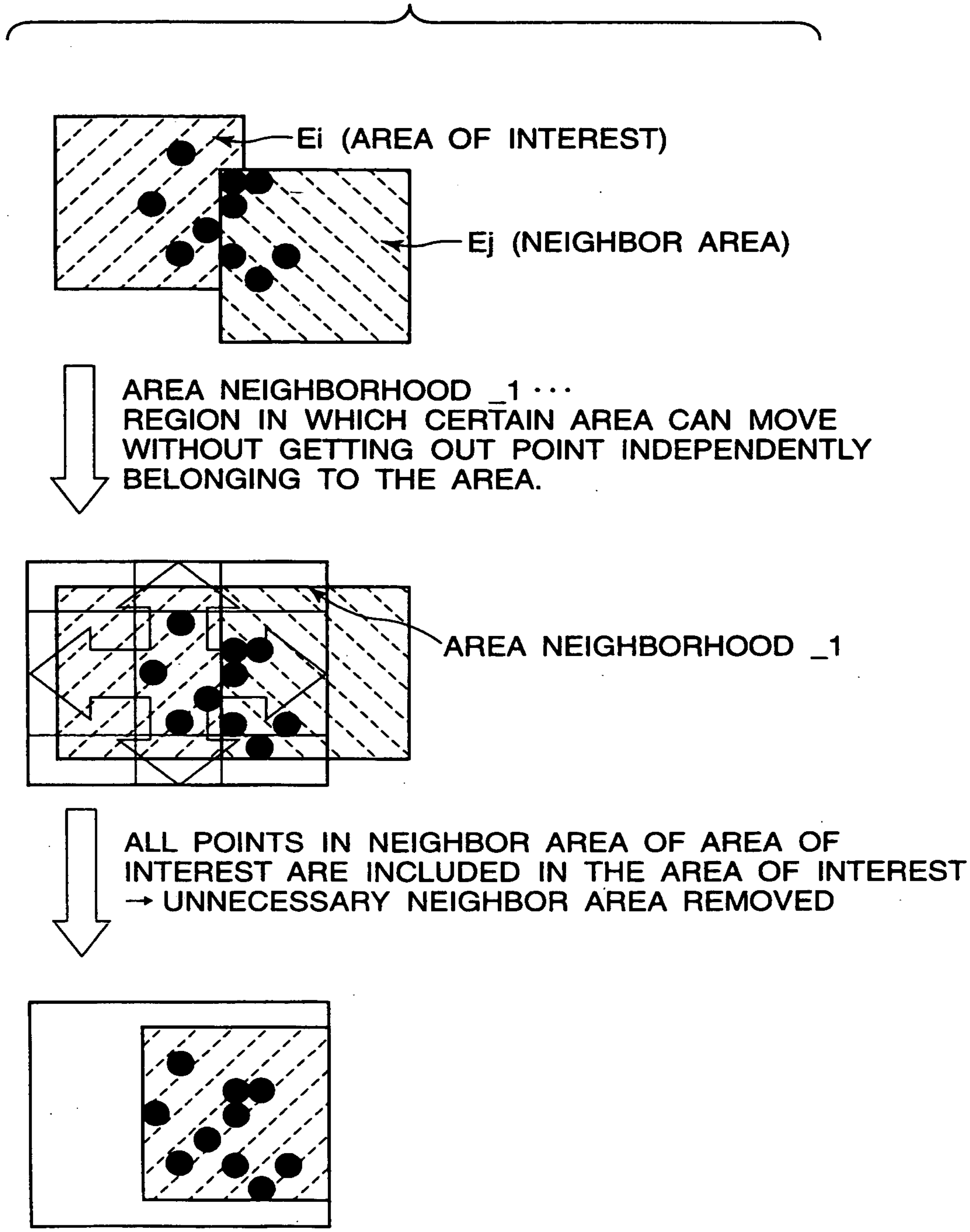

Ei (AREA OF INTEREST)
Ej (NEIGHBOR AREA)
AREA NEIGHBORHOOD _1 ···
REGION IN WHICH CERTAIN AREA CAN MOVE
WITHOUT GETTING OUT POINT INDEPENDENTLY
BELONGING TO THE AREA.
AREA NEIGHBORHOOD _1
ALL POINTS IN NEIGHBOR AREA OF AREA OF
INTEREST ARE INCLUDED IN THE AREA OF INTEREST
→ UNNECESSARY NEIGHBOR AREA REMOVED

FIG.37

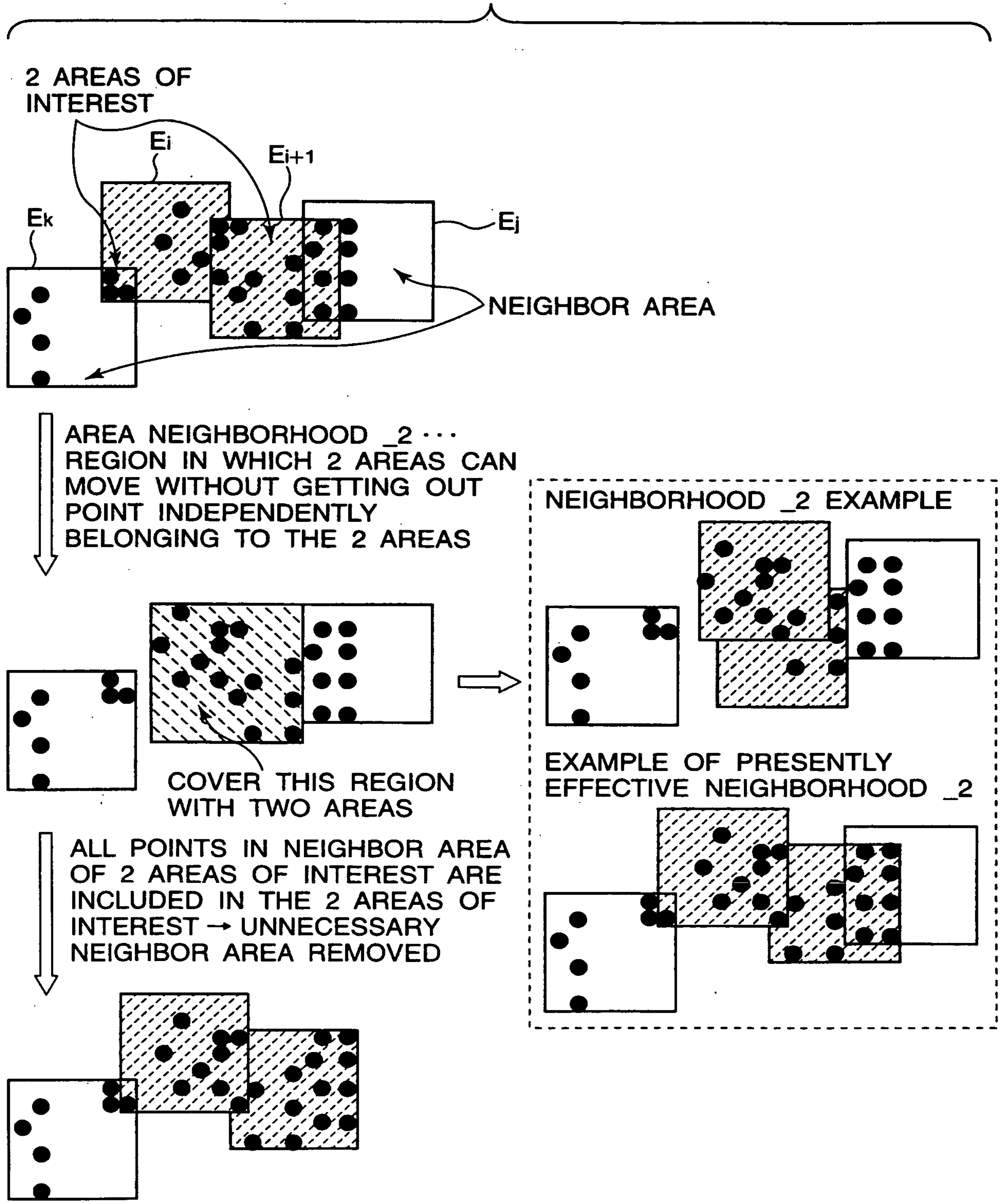

2 AREAS OF INTEREST
Ei
Ei+1
Ek
Ej
NEIGHBOR AREA
AREA NEIGHBORHOOD _2 ··· REGION IN WHICH 2 AREAS CAN MOVE WITHOUT GETTING OUT POINT INDEPENDENTLY BELONGING TO THE 2 AREAS
NEIGHBORHOOD _2 EXAMPLE
COVER THIS REGION WITH TWO AREAS
EXAMPLE OF PRESENTLY EFFECTIVE NEIGHBORHOOD _2
ALL POINTS IN NEIGHBOR AREA OF 2 AREAS OF INTEREST ARE INCLUDED IN THE 2 AREAS OF INTEREST → UNNECESSARY NEIGHBOR AREA REMOVED

FIG.38

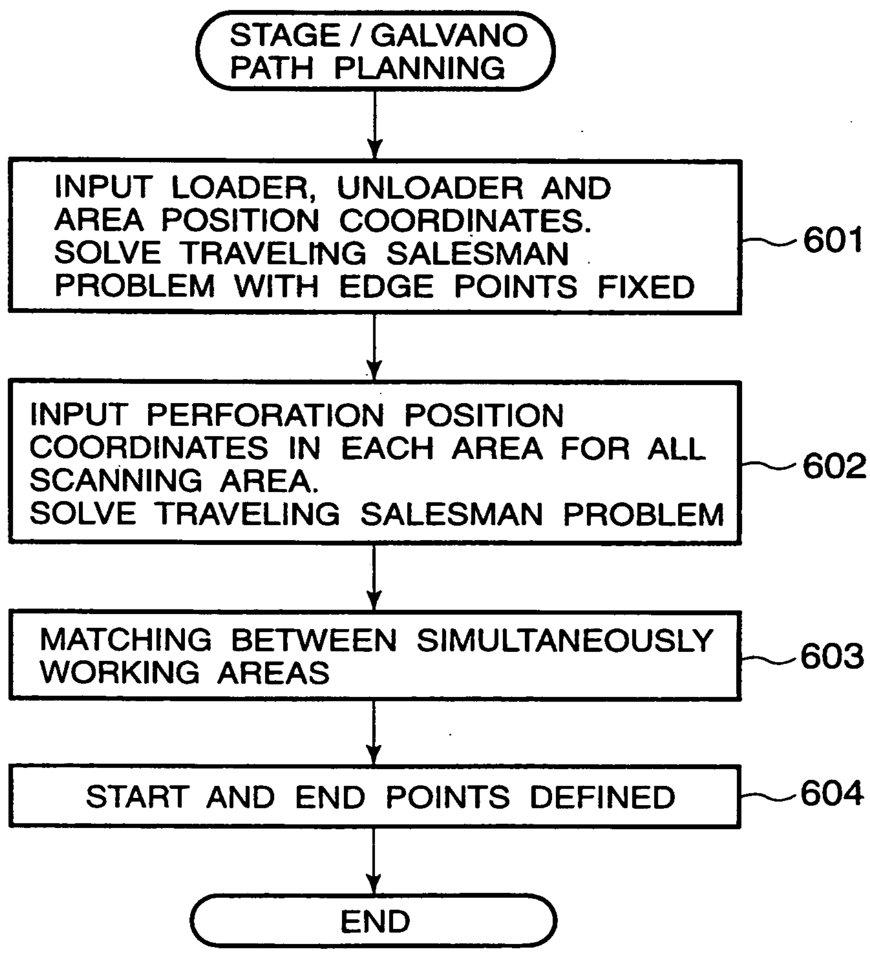

STAGE / GALVANO PATH PLANNING
INPUT LOADER, UNLOADER AND AREA POSITION COORDINATES. SOLVE TRAVELING SALESMAN PROBLEM WITH EDGE POINTS FIXED
601
INPUT PERFORATION POSITION COORDINATES IN EACH AREA FOR ALL SCANNING AREA. SOLVE TRAVELING SALESMAN PROBLEM
602
MATCHING BETWEEN SIMULTANEOUSLY WORKING AREAS
603
START AND END POINTS DEFINED
604
END

FIG.39

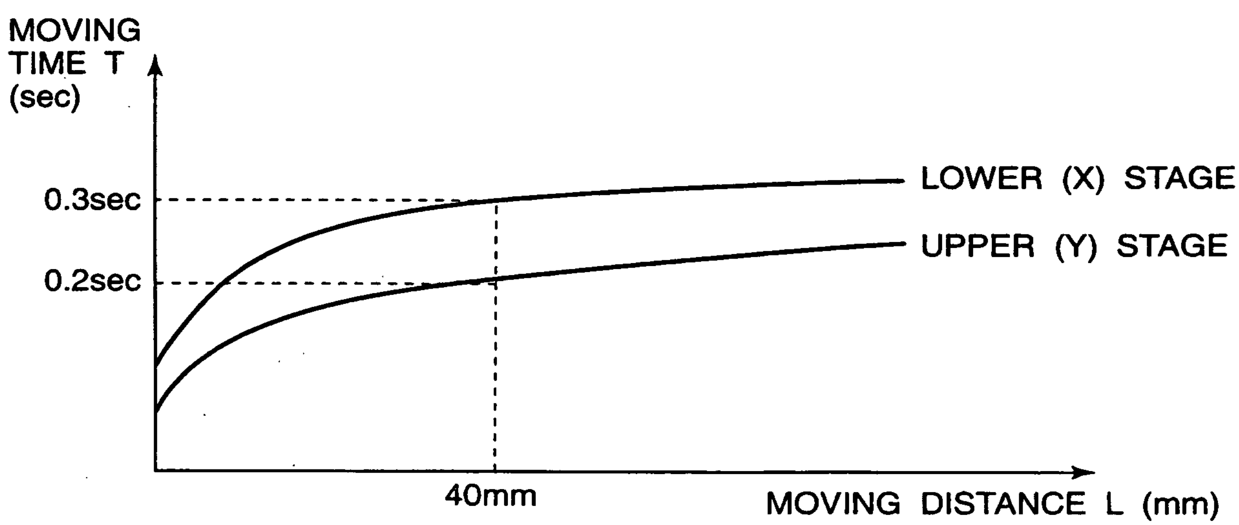

MOVING
TIME T
(sec)
0.3sec
0.2sec
LOWER (X) STAGE
UPPER (Y) STAGE
40mm
MOVING DISTANCE L (mm)

FIG.40

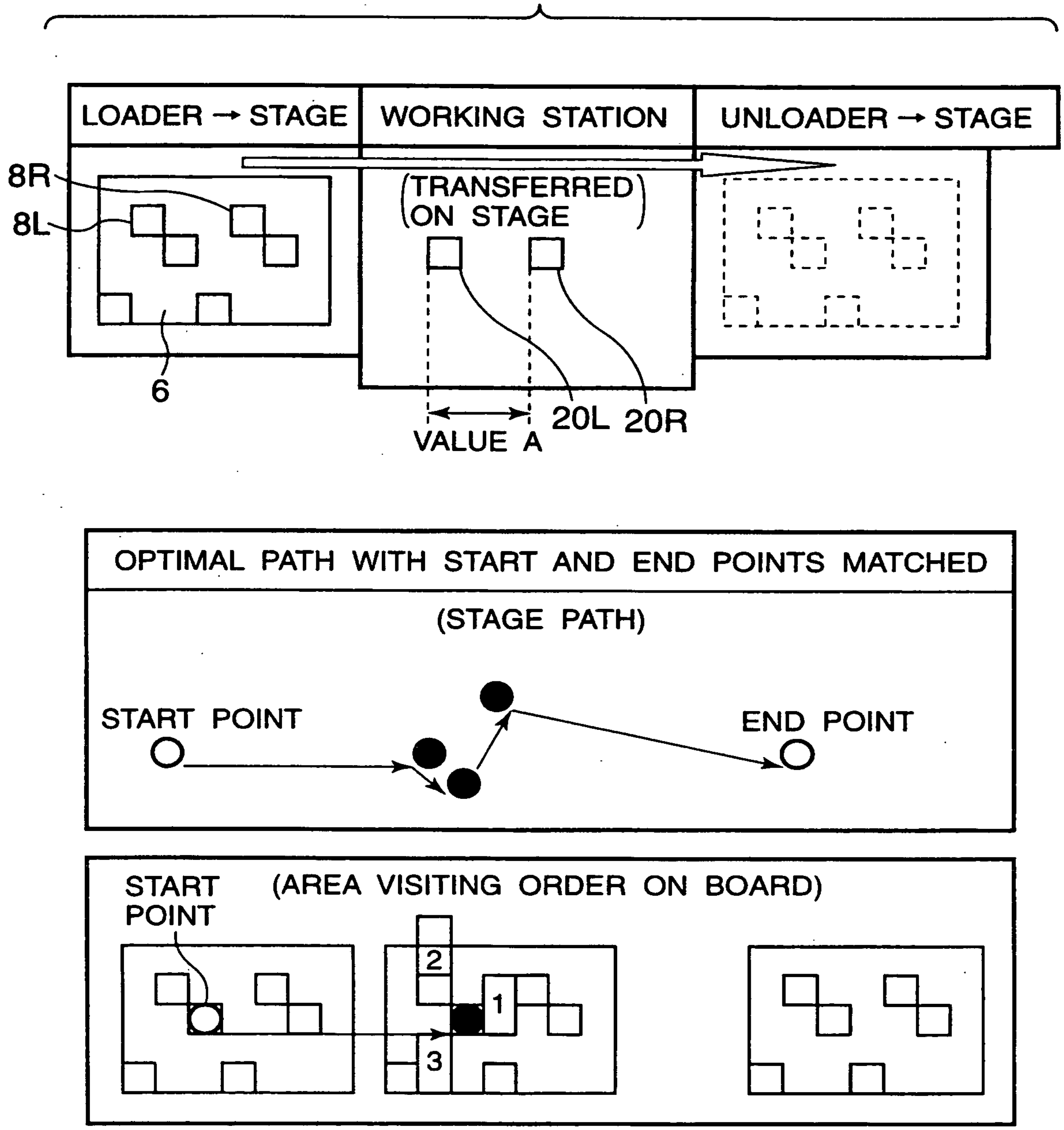

LOADER → STAGE
WORKING STATION
UNLOADER → STAGE
8R
8L
6
(TRANSFERRED ON STAGE)
VALUE A
20L
20R
OPTIMAL PATH WITH START AND END POINTS MATCHED
(STAGE PATH)
START POINT
END POINT
START POINT
(AREA VISITING ORDER ON BOARD)
2
1
3

FIG.41

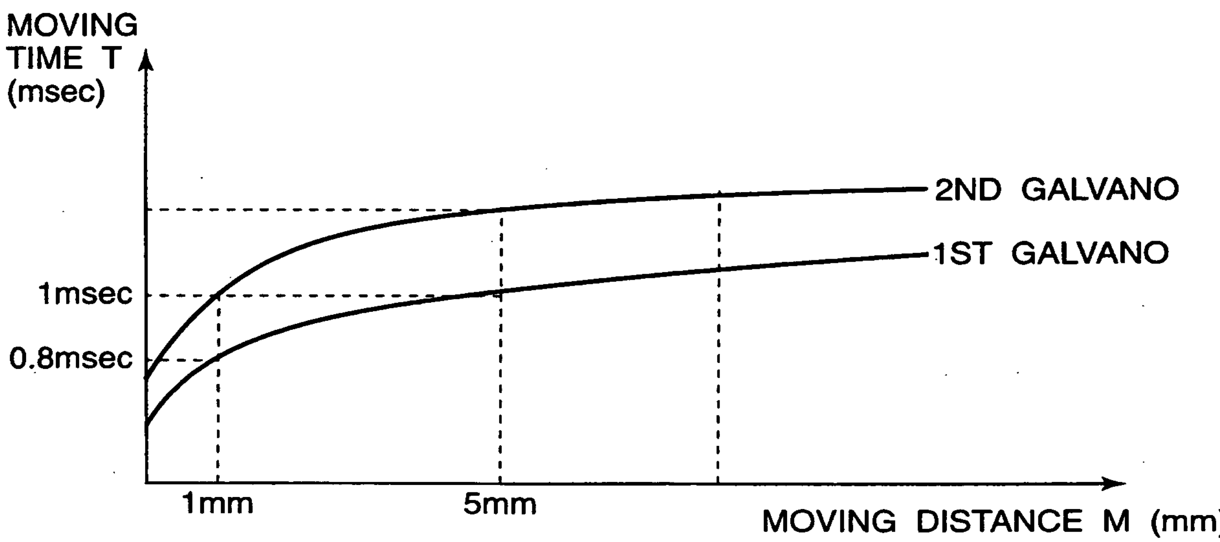

MOVING
TIME T
(msec)
2ND GALVANO
1ST GALVANO
1msec
0.8msec
1mm
5mm
MOVING DISTANCE M (mm)

FIG.42

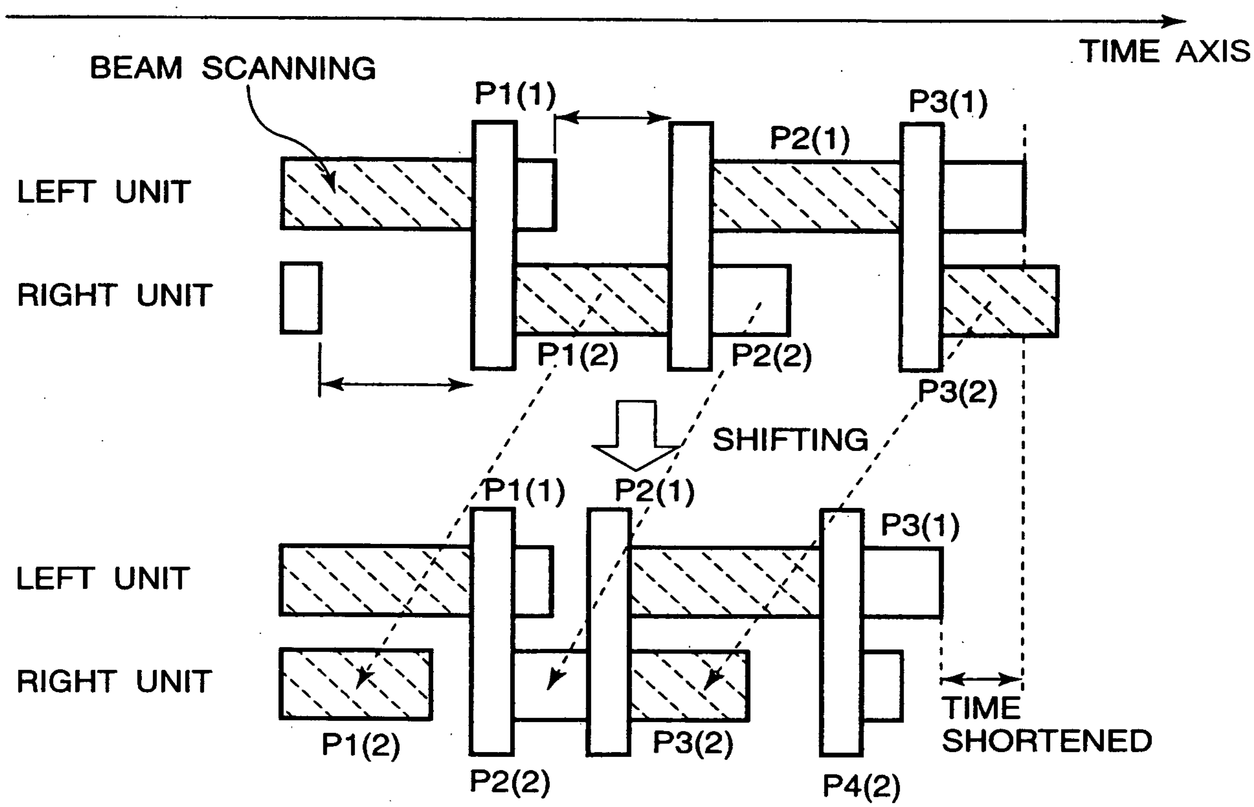

TIME AXIS
BEAM SCANNING
P1(1)
P3(1)
P2(1)
LEFT UNIT
RIGHT UNIT
P1(2)
P2(2)
P3(2)
SHIFTING
P1(1)
P2(1)
P3(1)
LEFT UNIT
RIGHT UNIT
P1(2)
P2(2)
P3(2)
P4(2)
TIME
SHORTENED

FIG.43

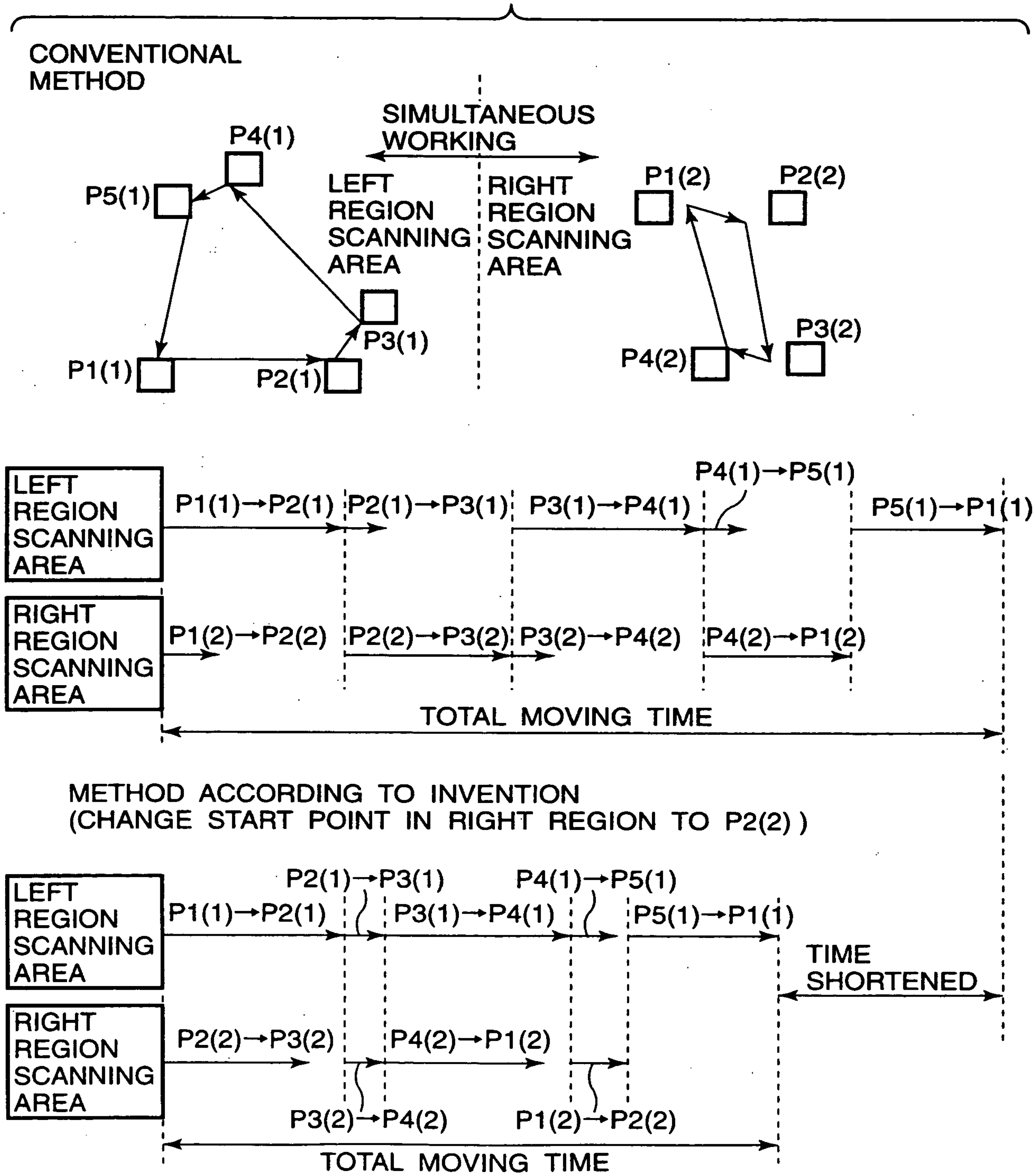

CONVENTIONAL METHOD
SIMULTANEOUS WORKING
LEFT REGION SCANNING AREA
RIGHT REGION SCANNING AREA
P1(1)
P2(1)
P3(1)
P4(1)
P5(1)
P1(2)
P2(2)
P3(2)
P4(2)
LEFT REGION SCANNING AREA
P1(1)→P2(1)
P2(1)→P3(1)
P3(1)→P4(1)
P4(1)→P5(1)
P5(1)→P1(1)
RIGHT REGION SCANNING AREA
P1(2)→P2(2)
P2(2)→P3(2)
P3(2)→P4(2)
P4(2)→P1(2)
TOTAL MOVING TIME
METHOD ACCORDING TO INVENTION
(CHANGE START POINT IN RIGHT REGION TO P2(2))
LEFT REGION SCANNING AREA
P1(1)→P2(1)
P2(1)→P3(1)
P3(1)→P4(1)
P4(1)→P5(1)
P5(1)→P1(1)
TIME SHORTENED
RIGHT REGION SCANNING AREA
P2(2)→P3(2)
P3(2)→P4(2)
P4(2)→P1(2)
P1(2)→P2(2)
TOTAL MOVING TIME

FIG.44

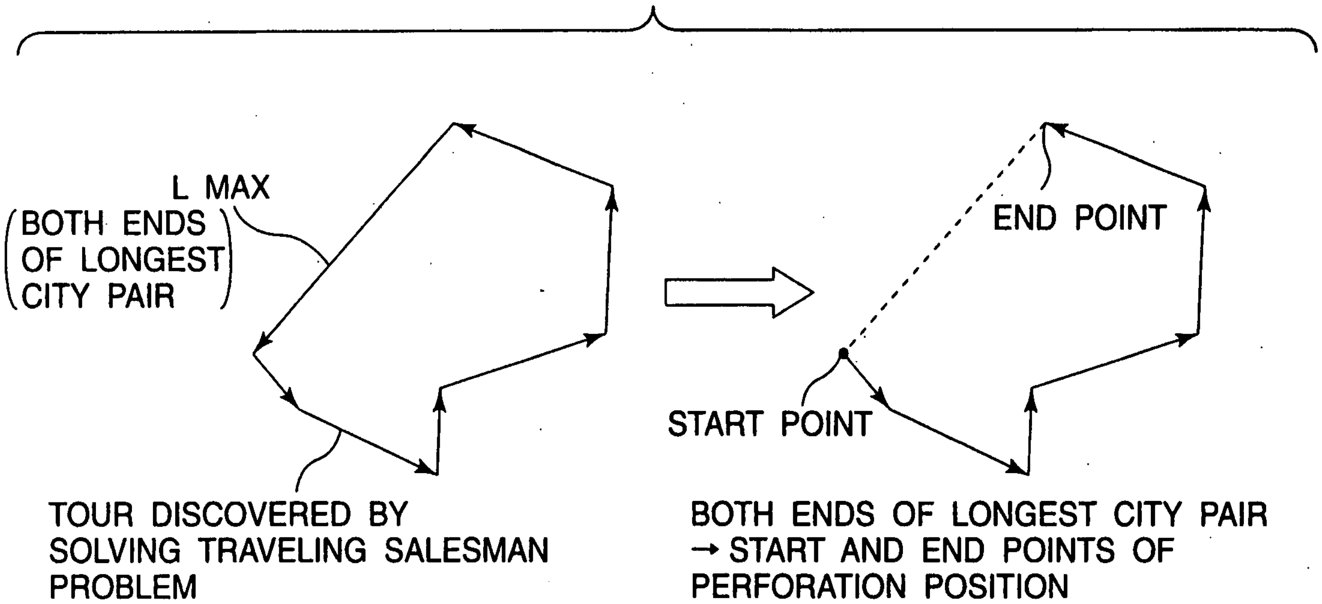

L MAX
(BOTH ENDS OF LONGEST CITY PAIR)
END POINT
START POINT
TOUR DISCOVERED BY SOLVING TRAVELING SALESMAN PROBLEM
BOTH ENDS OF LONGEST CITY PAIR → START AND END POINTS OF PERFORATION POSITION

FIG.45

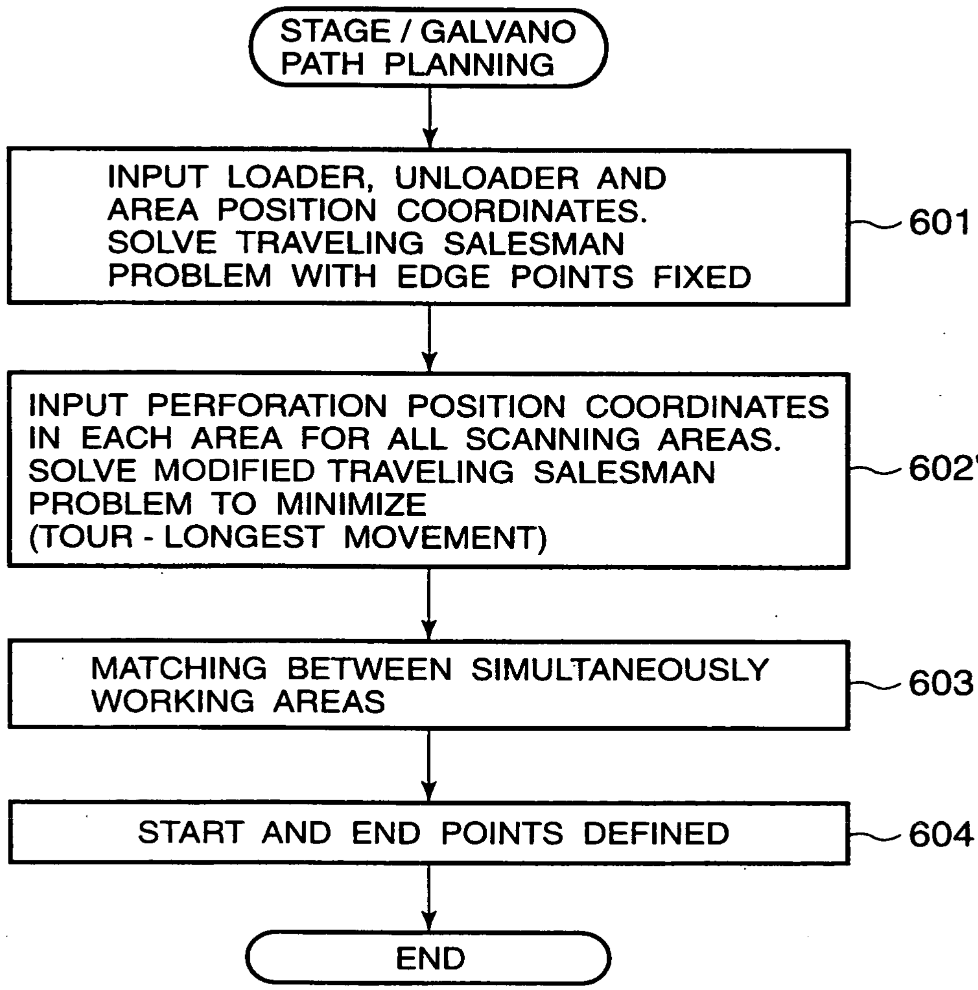

STAGE / GALVANO PATH PLANNING
INPUT LOADER, UNLOADER AND AREA POSITION COORDINATES. SOLVE TRAVELING SALESMAN PROBLEM WITH EDGE POINTS FIXED
601
INPUT PERFORATION POSITION COORDINATES IN EACH AREA FOR ALL SCANNING AREAS. SOLVE MODIFIED TRAVELING SALESMAN PROBLEM TO MINIMIZE (TOUR - LONGEST MOVEMENT)
602'
MATCHING BETWEEN SIMULTANEOUSLY WORKING AREAS
603
START AND END POINTS DEFINED
604
END

FIG.46

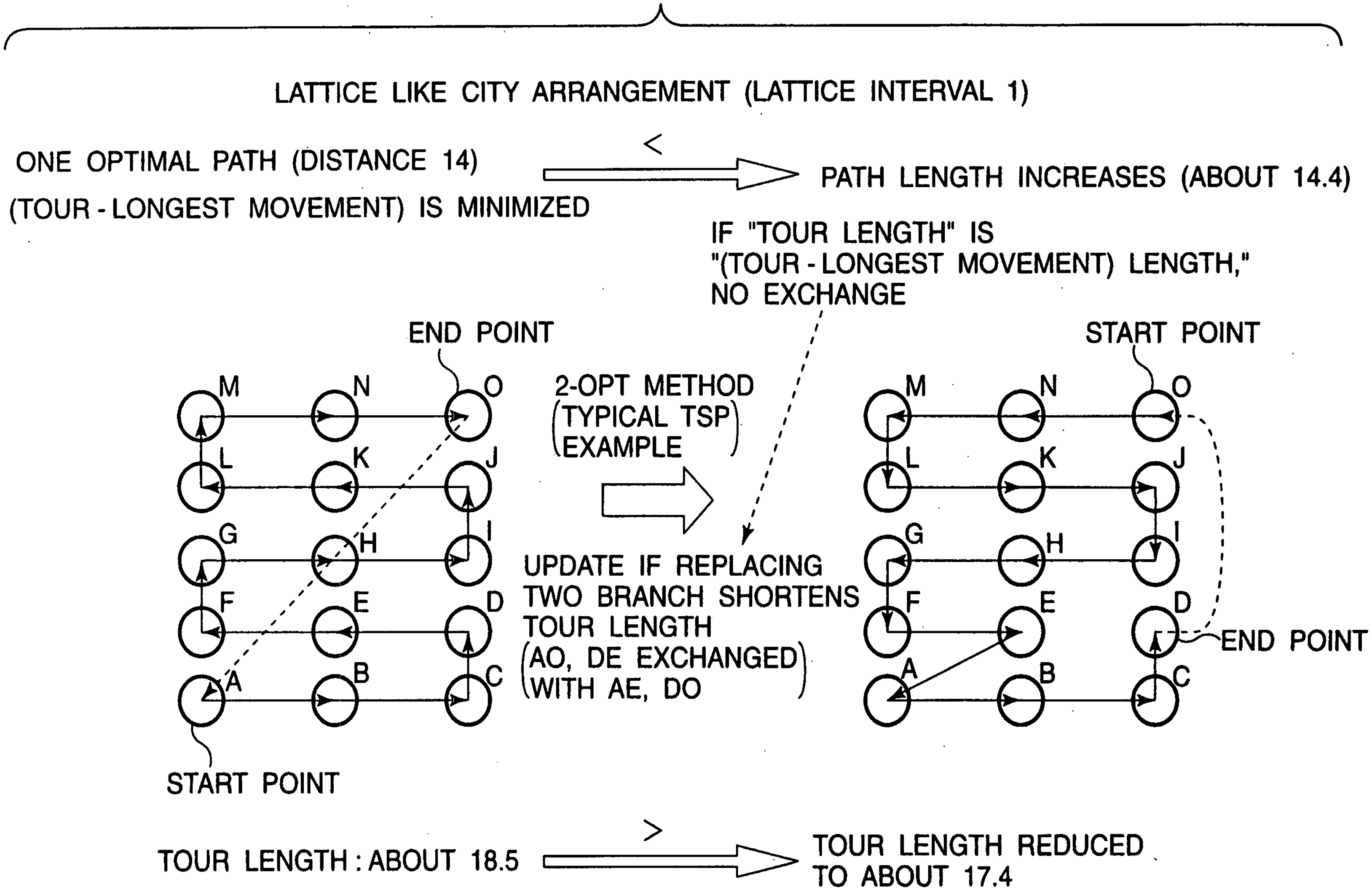
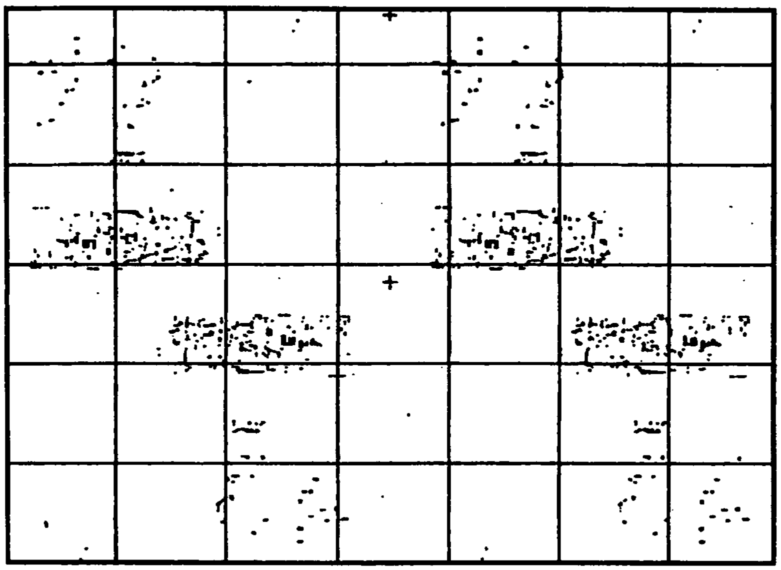
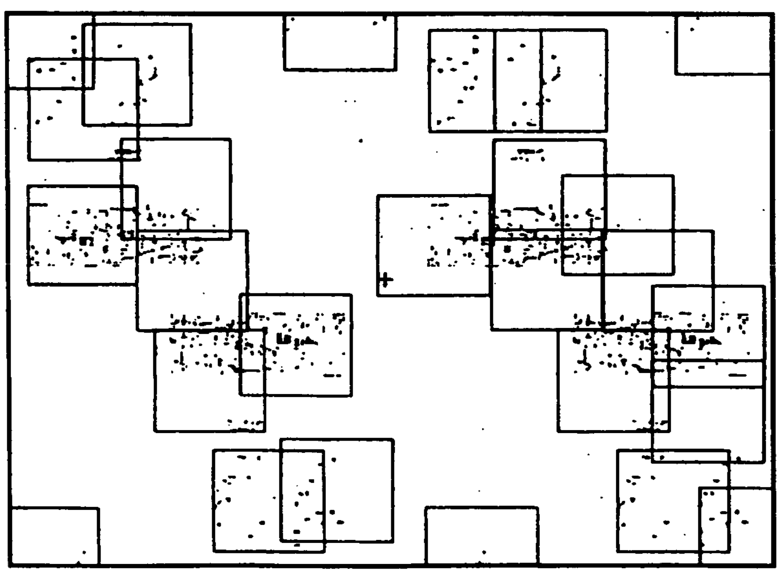

LATTICE LIKE CITY ARRANGEMENT (LATTICE INTERVAL 1)
ONE OPTIMAL PATH (DISTANCE 14)
(TOUR - LONGEST MOVEMENT) IS MINIMIZED
<
PATH LENGTH INCREASES (ABOUT 14.4)
IF "TOUR LENGTH" IS
"(TOUR - LONGEST MOVEMENT) LENGTH,"
NO EXCHANGE
END POINT
M
N
O
L
K
J
G
H
I
F
E
D
A
B
C
START POINT
2-OPT METHOD
(TYPICAL TSP EXAMPLE)
UPDATE IF REPLACING
TWO BRANCH SHORTENS
TOUR LENGTH
(AO, DE EXCHANGED WITH AE, DO)
START POINT
M
N
O
L
K
J
G
H
I
F
E
D
END POINT
A
B
C
TOUR LENGTH : ABOUT 18.5
>
TOUR LENGTH REDUCED
TO ABOUT 17.4

FIG.47

BOARD 1



CONVENTIONAL CASE (42 AREAS)



PRESENT INVENTION APPLIED (26 AREAS)

FIG.48

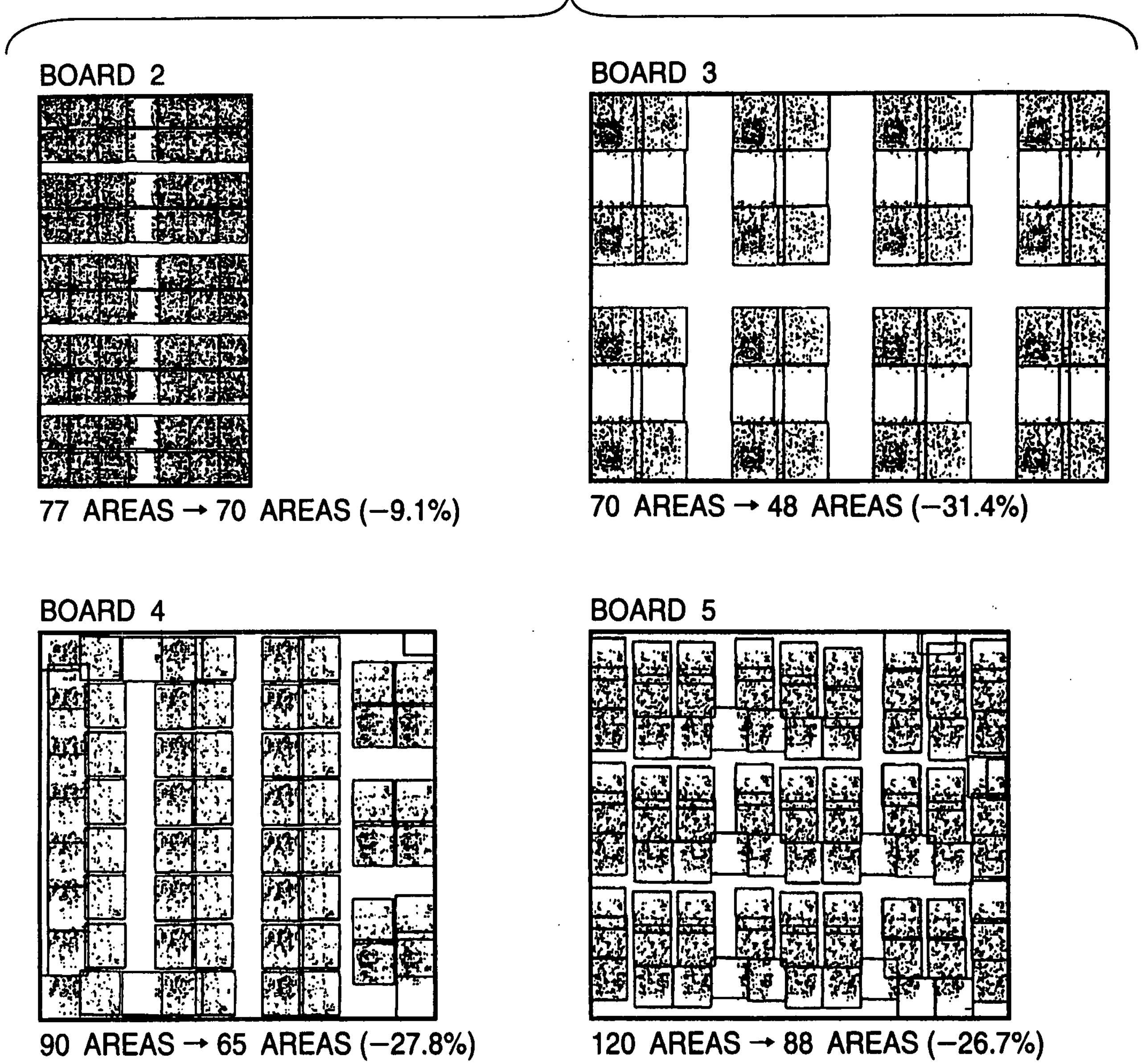

BOARD 2
77 AREAS → 70 AREAS (−9.1%)
BOARD 3
70 AREAS → 48 AREAS (−31.4%)
BOARD 4
90 AREAS → 65 AREAS (−27.8%)
BOARD 5
120 AREAS → 88 AREAS (−26.7%)

FIG.49

	PERFORATION POSITION NUMBER	CONVENTIONAL METHOD	PRESENT INVENTION	REDUCTION PERCENTAGE (%)
BOARD 1	2746	42	26	38.1
BOARD 2	39640	77	70	9.1
BOARD 3	11904	70	48	31.4
BOARD 4	15278	90	65	27.8
BOARD 5	17886	120	88	26.7

FIG.51

	UNIT DISTANCE (mm)	BEAM SCANNING NUMBER	STAGE MOVING NUMBER
HALVING (CONVENTIONAL METHOD 1)	220.88	26111	71
HEAD OF PATTERN (CONVENTIONAL METHOD 2)	242.29	26900	71
OPTIMAL POSITION (PRESENT INVENTION)	211.34	24555	71

FIG.54

PERFORATION POSITION NUMBER	CONVENTIONAL METHOD	METHOD ACCORDING TO INVENTION	IMPROVEMENT
100	4519	2838	62.8
500	1697	1190	70.1
1000	1445	849	58.8
(UNIT)	μm	μm	%

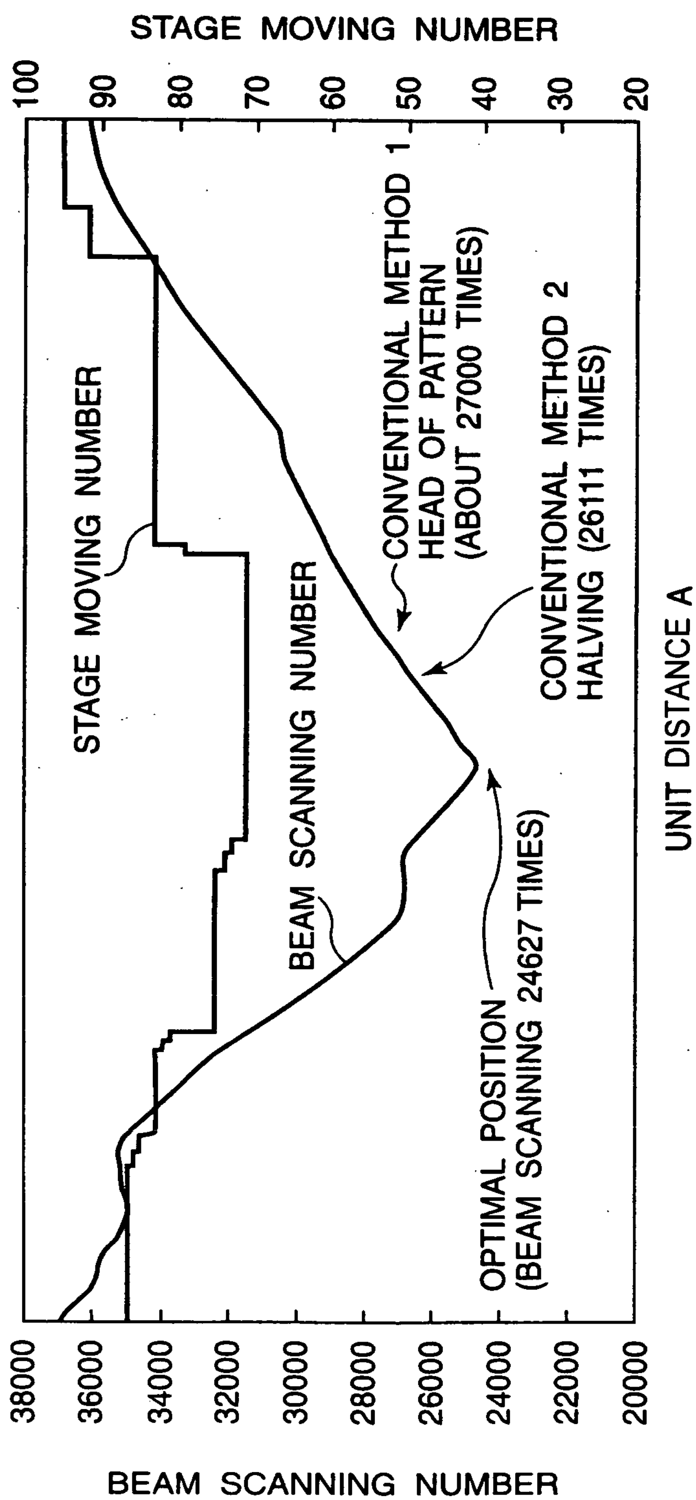
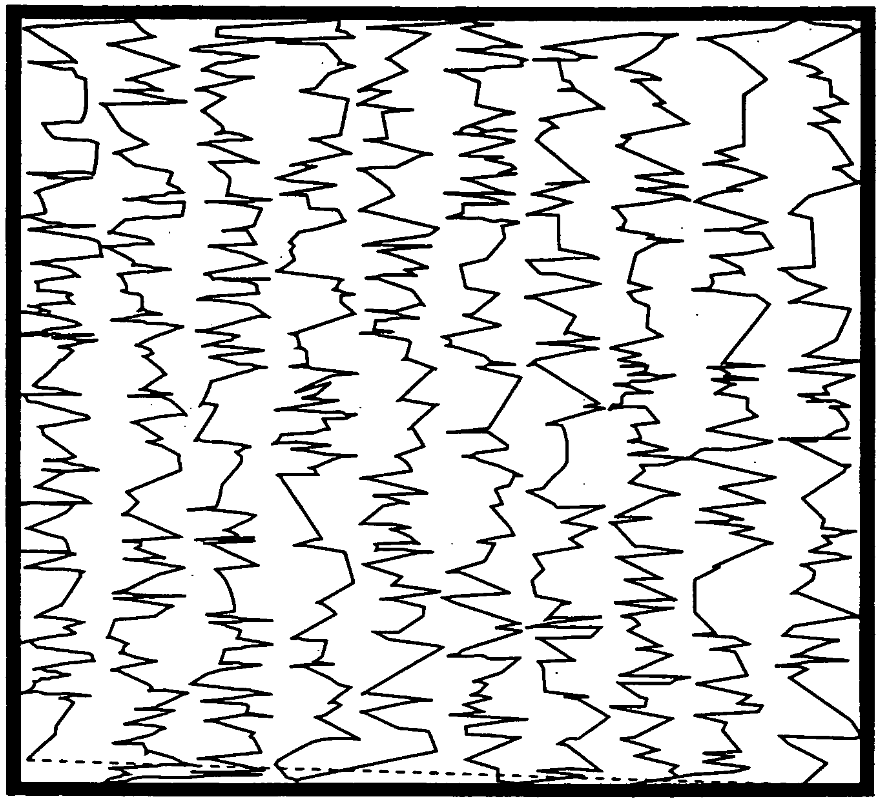
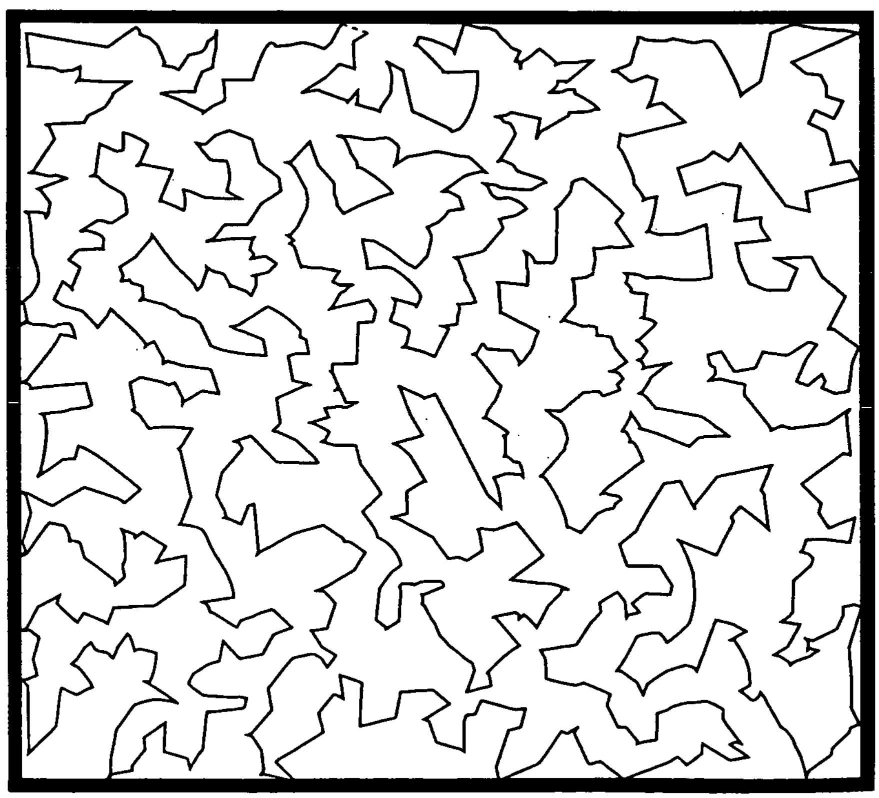

STAGE MOVING NUMBER
100
90
80
70
60
50
40
30
20
STAGE MOVING NUMBER
BEAM SCANNING NUMBER
CONVENTIONAL METHOD 1
HEAD OF PATTERN
(ABOUT 27000 TIMES)
CONVENTIONAL METHOD 2
HALVING (26111 TIMES)
BEAM
OPTIMAL POSITION
(BEAM SCANNING 24627 TIMES)
UNIT DISTANCE A
38000
36000
34000
32000
30000
28000
26000
24000
22000
20000
BEAM SCANNING NUMBER

FIG.50

FIG.52



CONVENTIONAL PATH



PATH AFTER PRESENT INVENTION IS APPLIED
(ACCORDING TO 3-OPT METHOD)

FIG.53

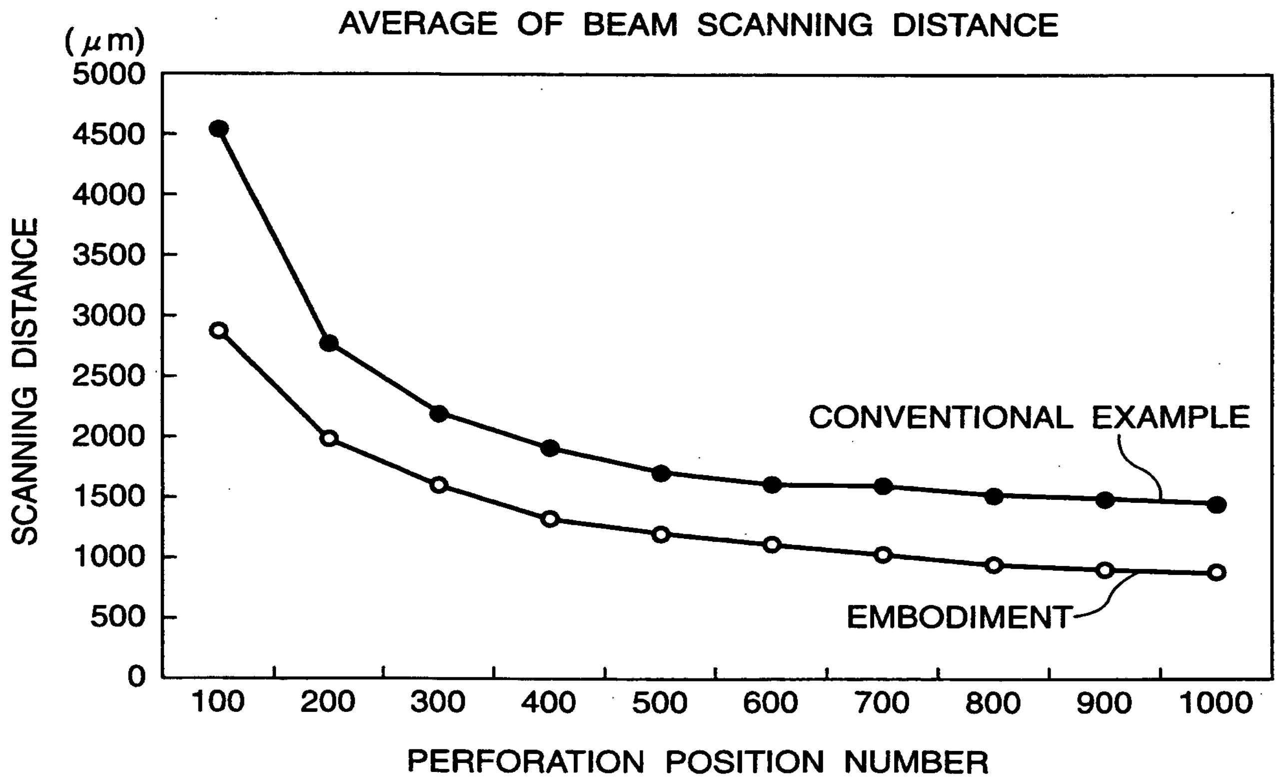
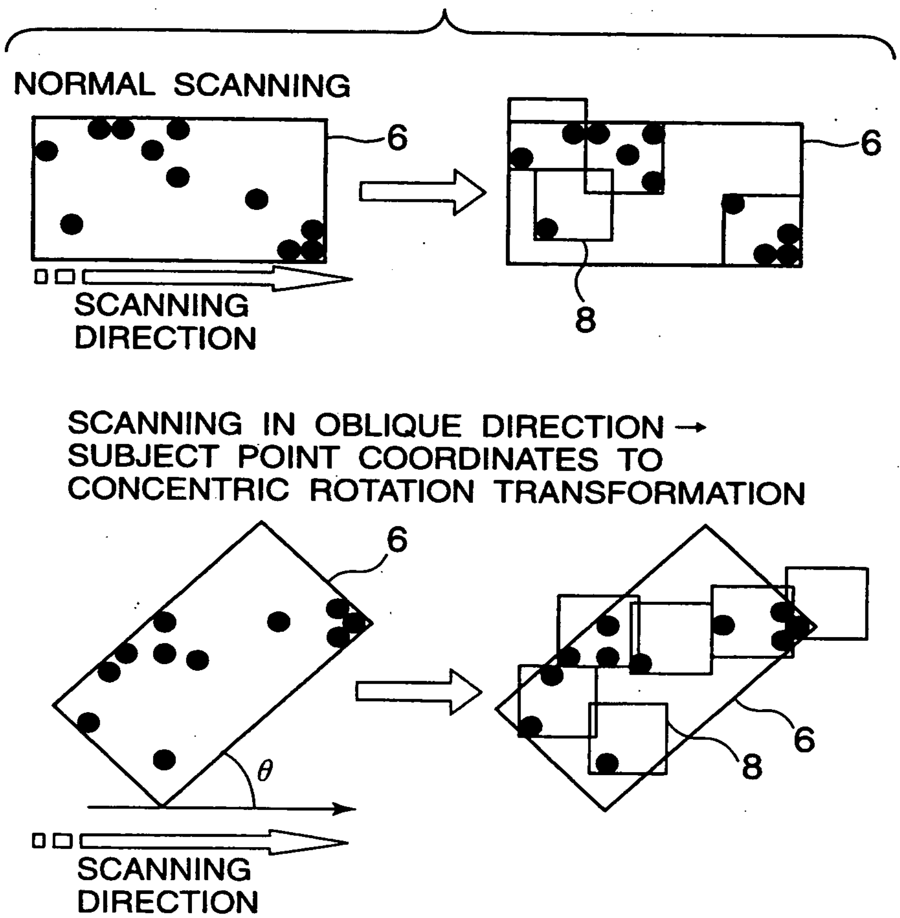

AVERAGE OF BEAM SCANNING DISTANCE
(μm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
SCANNING DISTANCE
CONVENTIONAL EXAMPLE
EMBODIMENT
100
200
300
400
500
600
700
800
900
1000
PERFORATION POSITION NUMBER

FIG. 55


NORMAL SCANNING
6
6
8
SCANNING
DIRECTION
SCANNING IN OBLIQUE DIRECTION →
SUBJECT POINT COORDINATES TO
CONCENTRIC ROTATION TRANSFORMATION
6
θ
6
8
SCANNING
DIRECTION